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ROLE OF FENCING IN PROMOTING WILDLIFE UNDERPASS USE AND HIGHWAY PERMEABILITY

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Abstract: Ungulate-proof fencing has been used successfully to mitigate the incidence of wildlife-vehicle collisions on highways throughout North America. And while fencing is often regarded as an integral component of effective wildlife passage structures, limited information or guidelines exist for the application of fencing in conjunction with wildlife passages. Fencing itself may limit wildlife permeability across highways and exacerbate the barrier effect of highways on wildlife populations. An 8-km section of highway reconstructed from a two- to four-lane divided highway in central Arizona was opened to traffic six months before ungulate-proof fencing was erected linking four wildlife underpasses (UP) and three bridges. To assess the role of strategically placed fencing along 49% of the section, we compared before and after fencing Rocky Mountain elk (*Cervus elaphus nelsoni*)-vehicle collision incidence, wildlife use of UP, and elk highway permeability. From 2002–2006, we documented 110 elk-vehicle collisions. The incidence of collisions increased over three fold after highway reconstruction was completed but before fencing was erected. After fencing, the incidence of elk collisions declined 87%. We employed video camera surveillance systems at two UP to compare wildlife use for nine months before and 11 months after fencing was erected. Before fencing, we recorded 500 elk and deer (*Odocoileus* spp.) at the UP, of which only 12% successfully passed through the UP; 81% of animals continued to cross the highway at grade. After fencing, of 595 elk and deer recorded, 56% crossed successfully and no animals crossed the highway at grade. The probability of an approaching animal crossing through an UP increased from 0.09 to 0.56 with fencing, and the combined odds of a crossing through the UP after fencing was 13.6:1 compared to before fencing. We used Global Positioning System (GPS) telemetry to assess highway permeability and crossing patterns. We instrumented 22 elk (16 female, 6 male) with GPS receiver collars April 2004–October 2005, during which time our collars accrued 87,745 GPS fixes. The elk highway passage rate, our measure of permeability, after the highway was opened to traffic but before fencing was erected (0.54 crossings/approach) was 32% lower than the level determined from a previous study for the section during reconstruction (0.79 crossings/approach). Once fencing was erected, the passage rate increased 52% to 0.82 crossings/approach. The proportion of elk crossings that occurred along fenced highway stretches declined 50% while the proportion of crossings along unfenced highway increased 40%. Fencing plays an important role in reducing the incidence of wildlife-vehicle collisions and increasing the effectiveness of wildlife passage structures. Furthermore, fencing in combination with a relatively high density of passages (1 structure/1.1 km) promoted elk highway permeability by funneling animals toward the UP where resistance to crossing was lower than that associated with crossings at grade.

Introduction

The awareness and understanding of highway impacts to wildlife populations in North America have increased dramatically in the past decade (Forman et al. 2003), with highways considered one of the most significant forces altering natural ecosystems (Noss and Cooperrider 1994, Trombulak and Frissell 2000, Farrell et al. 2002). Forman and Alexander (1998) estimated that highways have affected >20% of the land area within the U.S. through habitat loss and degradation. In addition to direct habitat loss (Forman 2000), mortality from vehicle collisions has been recognized as posing a serious and growing problem for wildlife, motorist safety, and property loss (Reed et al. 1982, Farrell et al. 2002). Estimates of annual vehicle collisions involving deer (Odocoileus spp.) alone in the U.S. have ranged as high as 1.5 million (Conover 1997). Wildlife-vehicle collisions cause human injuries, deaths, and tremendous property loss (Reed et al. 1982, Schwabe and Schuhmann 2002).

An even more pervasive impact of highways on wildlife is indirect barrier and fragmentation effects resulting in diminished habitat connectivity and permeability (Noss and Cooperrider 1994, Forman and Alexander 1998, Forman 2000, Forman et al. 2003). Highways act as barriers to free movement of wildlife, fragmenting and isolating habitats, limiting juvenile dispersal (Beier 1995), and reducing genetic interchange (Epps et al. 2005). Long-term fragmentation and isolation increases population susceptibility to stochastic events (Swihart and Slade 1984, Forman and Alexander 1998, Trombulak and Frissell 2003).

Just as our understanding of highway impacts has increased in the past decade, so have comprehensive efforts to mitigate and address these impacts in conjunction with highway construction and maintenance projects. Structures designed to promote wildlife passage across highways are increasingly being implemented and shown to be effective throughout North America, particularly large bridges (e.g., underpasses or overpasses) designed specifically for large animal passage (Foster and Humphrey 1995, Clevenger and Waltho 2003, Gordon and Anderson, 2003, Dodd et al. 2007a). Transportation agencies are increasingly receptive to integrating passage structures into highways to address both safety and ecological needs (Farrell et al. 2002) and there is increasing expectation that such structures will yield benefit to multiple species and enhance connectivity (Clevenger and Waltho 2000).

Ungulate-proof fencing ranging in height from 2.0–2.4 m has been demonstrated as effective in reducing the incidence of wildlife-vehicle collisions (WVC), especially when used in conjunction with passage structures (Romin and Bissonette 1996, Forman et al. 2003). Ward (1982) reported >90% reduction in mule deer (O. heminous) collisions with vehicles where underpasses and fencing were applied in Wyoming, though modifications to the original fencing were needed to achieve this reduction in WVC. Woods (1990) reported 94–97% reductions in WVC involving several species in Alberta with passages and fencing, while Clevenger et al. (2001) reported an 80% reduction in the same area. Similar reductions in moose (Alces alces)-vehicle collisions in Sweden were attained with fencing (Lavsund and Sandegren 1991).

Though fencing is generally regarded as effective in reducing WCV, mixed results nonetheless have been reported (Falk et al. 1978), especially where animals cross at the ends of fencing resulting in zones of increased incidence of WVC

(Feldhammer et al. 1986, Woods 1990, Clevenger et al. 2001). Furthermore, fencing is costly and requires substantial maintenance (Forman et al. 2003), potentially contributing to reluctance on the part of transportation managers to fencing extensive stretches of highways. And while fencing is often regarded as an integral component of effective passage structures (Romin and Bissonette 1996, Forman et al. 2003), limited information or guidelines exist for the application of fencing in conjunction with wildlife passages. Inasmuch as fences themselves constitute effective barriers to ungulate passage across highways (Falk et al. 1978), fencing may potentially exacerbate the reduction in wildlife permeability associated with highways alone (Dodd et al. 2007b), particularly where effective measures to accommodate animal passage are lacking.

Since 2000, the Arizona Department of Transportation (ADOT) has been reconstructing a 30-km stretch of State Route 260 (SR 260) in central Arizona, with plans to ultimately construct 11 sets of wildlife underpass (UP) and six sets of bridges. ADOT's general model for integrating 2.4-m ungulate-proof fencing with UP was to erect limited (<100 m) wing fences outward from each UP and most bridge abutments to funnel animals toward the structures. An adaptive management approach to reconstruction has been embraced by ADOT where data from our research has been used to make modifications to UP design (Dodd et al. 2007a) and the strategic placement of fencing to intercept crossing wildlife as determined from Global Positioning System (GPS) telemetry (Dodd et al. 2007b).

On our study section of SR 260, the highway was opened to traffic six months before ungulate-proof fencing was erected along approximately half of the section. This provided us an opportunity to assess and compare wildlife response and use of the highway corridor and UP, as well as WVC patterns before and after fencing was erected. The majority of UP construction was completed approximately 14 months before the section was opened to traffic, providing time for animals to habituate to the seven passage structures prior to our study, consistent with ungulate habituation reported by Clevenger and Waltho (2003) and Dodd et al. (2007a).

During the period that this section was under reconstruction, Dodd et al. (2007b) conducted a GPS telemetry assessment of Rocky Mountain elk (Cervus elaphus nelsoni) movement and crossing patterns and permeability across the highway corridor. They found that the elk passage rate on the lone completed section opened to traffic (0.43 crossings/approach +/- 0.15 SE, *n* = 15 elk) was lower than the mean rate for two control sections (0.88 crossings/approach +/- 0.16, *n* = 15) and two sections under reconstruction (0.84 crossings/approach +/- 0.12, *n* = 22) including that associated with this study (0.79 crossings/approach +/- 0.09, *n* = 14). Thus, we were further presented the opportunity to compare permeability before (Dodd et al. 2007b) and after the study section was opened to traffic following construction, as well as before and after fencing was erected to limit elk crossings at grade and to funnel animals toward UP. Numerous studies have alluded to highway barrier effects on wildlife (e.g., see Forman et al. 2003, Dodd et al. 2007b), but none have yielded quantitative data relative to animal highway passage rates in an experimental (e.g., before and after reconstruction) context.

The objectives of our study were to take an integrated approach to assess and compare: 1) elk highway crossing patterns and permeability before and after the highway section was opened to traffic before fencing was erected, 2) elk highway crossing patterns and permeability before and after fencing was erected once the highway section was opened to traffic, 3) wildlife use of UP before and after fencing was erected, focusing on elk, mule deer and white-tailed deer (*O. virginianus couesii*), and 4) WVC patterns before and after fencing was erected. We attempted to determine to what degree fencing is necessary to achieve wildlife use of UP, and to develop recommendations on the use of fencing in conjunction with wildlife UP to maximize their effectiveness in reducing WVC and maintaining wildlife permeability.

Study Area

Our study was conducted as part of the reconstruction of a 30-km stretch of SR 260, beginning 15 km east of Payson and extending to the base of the Mogollon Rim in central Arizona (lat 34o15'–34o18'N, long 110o15'–111o13'W; fig. 1). The existing two-lane highway is in the process of being reconstructed to a four-lane divided highway; in places, the footprint of the upgraded highway exceeds 0.5 km in width. Reconstruction of three of five sections has been completed, with seven of 11 planned UP and all six bridges completed (fig. 1). (Note: all figures are presented at end of paper.) The first section, Preacher Canyon, was completed and all lanes opened to traffic in November 2001, with two wildlife UP in addition to a large bridge over Preacher Canyon (fig. 1). The Kohl's Ranch section was the most recently reconstructed section, completed in March 2006; this section includes one UP and 2 bridges. Highway reconstruction of the last two sections, Little Green Valley and Doubtful Canyon will not occur before 2007.

We conducted this aspect of our study along the 8-km Christopher Creek (CC) section at which reconstruction was begun in early 2002. This reconstruction incorporated four wildlife UP and three bridges (fig. 1, table 1). On average, a passage structure was located every 1.1 km along the section. The majority of heavy reconstruction, including bridge and UP construction was completed by May 2003, at which time wildlife could pass through them. Vehicular traffic was confined to a single set of lanes until early-July 2004, when all four lanes were opened to traffic. Erection of ungulate-proof fencing was not completed until mid-December 2004. Original construction designs incorporated 2.4-m metal pipe, T-post, and mesh wire fencing adjacent to 1.8 km of the CC section (22%). This extent of fencing was increased to 3.9 km (49%; fig. 2) by raising the existing 1.1-m right-of-way (ROW) fence to 2.3 m through the adaptive management process to address peak elk highway crossing zones determined by GPS telemetry. The added fencing was projected to intercept 45% of elk crossings, for a total of 58% crossing interception by all fencing (Dodd et al. 2007b). During the extension of the ROW-fence, a 0.2-km gap was left in the fence midway along a 1.4-km stretch of fenced highway due to complexities associated with integrating fencing at a lateral access road into the community of Christopher Creek (fig. 2). Also, steep (4:1) fill slopes atop which ROW fence and guard rail were placed and tied into fencing with large boulder “elk rock” rip-rap (fig. 3) adjacent to 0.9 km of the highway was evaluated as an alternative treatment to deter at-grade wildlife crossings. This treatment was projected to intercept 27% if the GPS-identified elk crossings (Dodd et al. 2007b).

Our study area lies within the ponderosa pine (*Pinus ponderosa*) association of the montane coniferous forest community (Brown 1994a). Elevations range from 1,680-1,900 m. The Mogollon Rim escarpment to the north is the dominant landform, rising precipitously to 2,400 m (fig. 1). Numerous riparian and wet meadow habitats occur at several locations along the highway corridor (fig. 1), with some meadows >25 ha in size. Several perennial streams flow adjacent to portions of the highway (fig. 1). Climatic conditions within the study area are mild, with a mean maximum monthly temperature (July) for Payson of 32.4oC, and mean minimum monthly temperature (January) of -6.9oC. Annual precipitation averages 52.6 cm, with a mean of 54.1 cm of snowfall in winter; precipitation has averaged two-thirds of normal since 2002.

Average annual daily traffic (AADT) volume on this portion of SR 260 (ADOT Control Road traffic monitoring station) doubled in 10 years from 3,100 in 1994 to nearly 6,300 in 2002, and increased to 8,700 (+38%) in 2003 (ADOT Data Management Section). Over the same period, annual wildlife-vehicle collisions involving ungulates and large carnivores on this stretch of SR 260 increased from 28 to 44, with a mean of 35.9 (+/-2.5 SE; Dodd et al. 2006).

Table 1: Physical characteristics associated with wildlife underpasses (UP) and bridges on the Christopher Creek section of State Route 260, Arizona, USA

Passage structure	Span m (ft)	Rise m (ft)	Length m (ft)[a]	Atrium m (ft)[b]
Wildlife 1 UP	103.0 (338)	15.0 (49)	110.0 (361)	24.0 (79)
Christopher Creek bridge	158.5 (520)	17.7 (58)	91.4 (300)	20.0 (66)
Pedestrian/wildlife UP	34.2 (112)	6.8 (22)	128.0 (420)	47.9 (157)
Hunter Creek access UP	38.1 (125)	6.5 (21)	112.8 (370)	53.3 (175)
Wildlife 2 UP	39.9 (131)	10.0 (33)	118.8 (390)	31.9 (105)
Sharp Creek bridge				
Eastbound lanes	174.0 (571)	17.5 (57)	175.0 (574)	125.0 (410)
Westbound lanes	39.9 (131)	6.6 (22)		
Wildlife 3 UP	37.7 (124)	5.1 (17)	63.9 (210)	None

[a] Length = distance for animals to fully negotiate passage structure, from mouth to mouth including fill material
[b] Atrium = width of opening between eastbound and westbound bridge spans

Rocky Mountain elk (*Cervus elaphus nelsoni*) were a focus of our research for several reasons. First, elk accounted for >80% of all collisions between vehicles and wildlife (Dodd et al. 2006) and the vast majority of property loss and human injuries associated with collisions with vehicles. Elk are large animals that can readily support our GPS telemetry collars, yielding substantial data on movements in relation to the highway corridor, and were relatively easy to trap. Both resident and migratory elk herds 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, 1994b). Elk return to summer range with forage green up at higher elevations (Brown 1990). The Arizona Game and Fish Department estimated the resident elk population in game management units encompassing our study area at 1,500-1,600 (Arizona Game and Fish Department, Game Management Branch, unpublished data), though not all elk resided in proximity to SR 260. Whitetail deer (*Odocoileus virginianus cousei*) were frequently seen in our study area, while mule deer (*O. hemionus*) were less common and more localized on the CC section.

Methods

To address our study objectives, we used data collected during a previous phase of research conducted when the CC section was under reconstruction, yielding data on elk crossing patterns and passage rates determined from GPS telemetry (Dodd et al. 2007b) and WVC collision patterns (Dodd et al. 2006). We used these baseline data to make comparisons among the following three highway reconstruction treatment classes: 1) under reconstruction, 2) post reconstruction-before fencing (henceforth before fencing), and 3) post reconstruction-after fencing (henceforth after fencing). The availability of under reconstruction treatment data allowed us to make comparisons among all three treatment classes for our elk permeability and WVC patterns data. Our comparisons of UP wildlife use however were limited to before and after fencing, as the video camera surveillance systems we employed to assess wildlife use were not installed until after reconstruction was completed. Statistical tests were performed using the program STATISTICA® (Statsoft, Inc. 1994). Results were considered significant at $P \leq 0.05$. Mean values were reported with +/- one SE.

Comparison of Elk Crossing Patterns and Permeability

We captured and handled elk at six trap sites spaced an average of 1.1 km apart along the CC section and one site each on the Kohl's Ranch and Doubtful Canyon sections, similar to Dodd et al. (2007b). We trapped elk in net-covered Clover traps (Clover 1954) baited with salt and alfalfa hay, with all traps located within 300 m of the highway corridor. We timed trapping to target resident elk to maximize yearlong acquisition of GPS fixes near the highway. We used model TGW-3600 "store-on-board" GPS receiver collars (Telonics, Inc., Mesa, Arizona, USA) programmed to receive a fix every 1.5 hours from 1700–900 hours (12 fixes) and one at 1200; operational battery life was 22 months.

We employed ArcGIS® Version 8.3 software (ESRI, Redlands, California, USA) and Animal Movement ArcView Extension Version 1.1 software (Hooge and Eichenlaub 1997) to analyze GPS data similar to Dodd et al. (2007b). We divided the length of the CC section into 50 sequentially numbered 0.16-km segments (fig. 4) to quantify highway approaches and crossings. To infer highway crossings, we drew lines connecting all consecutive GPS fixes; crossings were identified where lines between fixes crossed the highway through a segment (fig. 4). We compiled crossings by individual animal by highway segment. We calculated crossing rates for individual elk by dividing the crossings by the days a collar was worn.

We calculated elk passage rates as per Dodd et al. (2007b); passage rates were considered our best relative measure of highway permeability (e.g., compared to crossing rates; Dodd et al. 2007b). An approach was considered to have occurred when an elk traveled (determined by successive GPS fixes) to within 0.25 km of SR 260 (fig. 4); successive fixes within 0.25 km of SR 260 were treated as a single approach. Our approach zone corresponded to the road-effect zone where elk were affected by traffic-related disturbance (Rost and Bailey 1979, Forman et al. 2003) and the zone adjacent to highways avoided by elk (Witmer and deCalesta 1985). We calculated passage rates for each elk as the proportion of highway crossings to approaches during the same period. We calculated and compared different rates for the periods before and after ungulate-proof fencing was erected. We also compared the elk passage rates determined by Dodd et al. (2007b) when the CC section was under reconstruction to those after reconstruction was completed (before and after fencing). Values were derived for individual elk and pooled for each comparison class.

We employed ANOVA to test the null hypothesis that no differences in elk passage rates existed among treatment classes. Where significant ANOVA results were obtained among classes, we conducted post hoc pairwise comparisons using a Tukey test for unequal sample sizes (Statsoft Inc. 1999, Dodd et al 2007b). We made similar comparisons for elk highway crossing rates among treatment classes.

To assess how fencing affected the elk crossing distribution patterns after reconstruction was completed, we compared the change in the proportions of crossings before and after fencing that occurred along the CC section for three crossing deterrent treatments: 1) fenced, 2) steep slopes-elk rock, and 3) not fenced (fig. 2). We compared the mean change in proportions of elk crossings that occurred along highway stretches between passage structures among the treatments. We made these comparisons with ANOVA, and where significant results were obtained, post hoc pairwise comparisons were done using a Tukey test for unequal sample sizes.

Comparison of Elk-Vehicle Collision Patterns

To document WVC along SR 260, we used consolidated records from multiple sources as described by Dodd et al. (2006). Our primary source was a long-term statewide accident database maintained by the ADOT Data Management Section (ADOT, unpublished data), including WVC. Records in this database included the date, time, and location of the WVC, and wildlife species (genus only in the case of deer) involved. From this database, we were also able to determine the proportion of total accidents through 2005 that involved collisions with wildlife. Further, at the onset of our project in late-2000, we developed a standardized WVC tracking form for use by agencies and research project personnel to document all WVC, including roadkills. This database reflected concerted efforts to regularly search for and document WVC, especially by research project personnel Our database included the same information as the ADOT database, including species of deer. All WVC were recorded to the nearest 0.16 km.

We compared the incidence of WVC involving elk only among treatments as ungulate-proof fencing, especially the modified ROW fence was permeable to deer and other species. We compared elk-vehicle collisions among treatments documented from 2002 (when reconstruction was begun) through 2006. We compiled elk-vehicle collision data by season (January–March, April–June, July–September, October–December) and highway treatment class. Season influenced elk UP (Dodd et al. 2006) and highway crossing patterns (Gagnon 2006), with the fall (October–December) migratory period accounting for the highest incidence of elk-vehicle collisions (Dodd et al. 2006). We used ANOVA to compare mean elk-vehicle collisions among seasons and highway treatments. Where significant results were obtained in our ANCOVA, post hoc pairwise comparisons were done using a Tukey test for unequal sample sizes.

Wildlife Underpass Use Comparison

We used triggered four-camera video surveillance systems described by Dodd et al. (2007a) and Gagnon et al. (2006) to examine the number of elk and deer that used UP on the CC section. These systems included two cameras that recorded animals approaching the UP from one side of the UP (approximately 40–50 m from the mouth of the UP) and the other two cameras recording animals as they passed through UP. Though video camera systems were installed at four UP on the CC Section, only two systems were installed prior to erection of fencing, limiting our before and after fencing comparison of UP wildlife use to the Pedestrian/Wildlife and Wildlife 2 UP (table 1, fig. 2) located 2.4 km apart. Both UP at which we compared wildlife use had separate east- and west-bound bridges with open atria between bridges (32–48 m; table 1).

We assessed and compared wildlife use at the two UP for nine months (April–December 2004) prior to fencing and 11 months (January–December 2005) after the erection of fencing to funnel animals to UP. We focused on elk, mule deer, and white-tailed deer since they comprised a majority of animals recorded by camera systems; fencing was permeable to smaller species. We used individual elk and deer as our sampling unit even though these ungulate species exhibit a herding nature, as individual animals within groups often exhibited different responses to approaching and crossing the two UP.

We considered an UP approach to occur when animals crossed over the 1.1-m ROW fence approximately 40–50 m from the mouth of the UP. We compared mean daily and monthly usage and overall probability of usage before and after erection of fencing. We assessed the number of animals that approached the UP and assigned them to two approach categories based on their subsequent behavior recorded by our cameras:

- *Attempted to cross* – animals that approached the highway corridor in the vicinity of the UP and attempted to cross the highway either via the UP or over the highway.
- *No attempt to cross* – animals that were recorded by cameras at the UP but appeared to have had no intention of crossing the highway.

Once we identified an animal as attempting to cross the highway, we assigned them to one of three crossing behavior categories and examined the proportion of crossings that fell within the categories:

- *Avoid UP altogether* – animals crossed up and over both sets of highway lanes at grade.
- *Partial crossing* – animals passed through one bridge below grade but entered the median between bridges via atria and crossed the other two lanes at grade.
- *Successful crossing* – animals crossed through both bridges and all lanes of traffic below grade.

We tested the overall hypothesis that probability of use and daily and monthly wildlife of the UP use did not differ before and after the erection of fencing. To test the hypothesis that probability of use was independent of fencing we examined the number of observed successful elk and deer crossings and compared them to expected using a chi-square contingency table. We used fencing as the treatment and successful crossing (yes/no) as our bivariate response variable. We also estimated the odds ratio and associated 95% confidence interval (CI) of an elk or deer using the UP, both combined and individually with and without fencing with a general linear model with a logit link (Agresti 1996). To test the hypothesis that mean daily and monthly use did not differ after fencing, we compared elk and deer use of the two UP for an equivalent 9-month period before and after fencing was erected. As these data were not normally distributed, we used a Mann-Whitney U-test to compare mean daily and monthly UP use by wildlife.

Results

Comparison of Elk Crossing Patterns and Permeability

We instrumented a total of 32 elk (25 female, 7 male) with GPS receiver collars between April 2004 and October 2005. Of these elk, 22 (16 female, 6 male) were relocated along the CC section and used in this analysis. All collars were recovered and data downloaded by June 2006. GPS collars were affixed to elk an average of 370.0 days (+/- 36.6; range = 84–662 days). Elk wore our collars more days after fencing was erected (5,175; n = 22 elk) than before (2,693; n = 16) due to various collar-related problems; 14 elk wore collars across both treatments. We accrued 87,745 GPS fixes, representing an 85.6% fix success (range = 31.9–100.0). We obtained a mean of 4,172.8 fixes/elk (+/- 484.2; range = 926–8,648); 64.2% (range = 52.2–75.4) of our fixes were 3-dimensional fixes. Of the GPS fixes our collars recorded, 42,542 (48.5%) occurred within 1.0 km of SR 260. On average, we obtained 5.1 fixes/day/elk (+/- 0.5) ≤1.0 km from the highway. Elk occurred within 0.25 km of the highway (approach distance) on 12,563 occasions with a mean of 571.0 fixes/elk (+/-107.3).

Our collared elk crossed the CC section 2,692 times, with a mean of 122.4 crossings/elk (+/- 25.3) that ranged from 14–402 crossings; 986 crossings occurred before and 1,706 crossings occurred after fencing was erected. The number of different elk crossing at each 0.16 km highway segment ranged from 1–13 and averaged 6.4 (+/- 0.5). Overall, elk crossed the highway 0.38 times/day compared to 0.28 crossings/day when the highway was under reconstruction (Dodd et al. 2007b: table 2). Post reconstruction, our elk crossed the highway an average of 0.38 times/day before and 0.35 times/day after fencing was erected on the CC section (table 2). Among the three treatments, there was no difference in highway crossing rates (ANOVA P = 0.618; table 2).

Compared to our mean elk passage rate of 0.79 while the CC section was under reconstruction (Dodd et al. 2007b; table 2), permeability was 31.6% lower, or 0.54 crossings/approach following reconstruction but before fencing was erected (table 2). Once fencing was erected, our passage rate rebounded 51.8% to 0.82 crossings/approach (table 2). Our ANOVA found differences among the treatment classes ($F_{2,44}$ = 3.33, P = 0.045). Both our mean passage rates for elk during reconstruction (*P* = 0.042) and after fencing was erected (*P* = 0.014) were higher than the rate after reconstruction but before fencing was erected (table 2).

We found differences in the proportions of elk crossings before and after fencing along highway stretches between passage structures among the three passage deterrent treatments (ANOVA $F_{2,5}$ = 7.27, *P* = 0.033; table 3). The mean proportion of elk crossings on the fenced stretches declined 50.0% after fencing was erected, from 0.20 to 0.10 (mean change = -0.10), which was lower (*P* = 0.045) than the mean change for unfenced stretches (table 3). On unfenced stretches the mean proportion of elk crossings increased 39.7% from 0.07 to 0.10 (mean change = 0.03; table 3) once fencing was erected; the proportion of crossings increased 106.2%, from 0.03 to 0.07 at the 0.2-km gap in the fence at the CC access road. On steep slopes with elk rock, the proportion of crossings increased 60.8% after fencing from 0.12 to 0.19, though the change in proportion of crossings here did not differ from fenced or unfenced stretches (table 3).

Table 2: Mean elk crossings/day and passage rate (crossings/approach) for elk fitted with Global Positioning System (GPS) telemetry collars by highway reconstruction treatment, Christopher Creek section, State Route 260, Arizona, USA. GPS telemetry conducted 2002–2004 for during reconstruction (Dodd et al. 2007b) and 2004–2006 for the post construction treatments. Letters denote significant differences for Tukey test pairwise construction class comparisons for significant ANOVA among classes

Highway reconstruction class	Elk *n*	Crossings/day (SE)	Passage rate[a] (SE)
During reconstruction	14	0.28 (0.07) A	0.79 (0.09) A
Post reconstruction – before fencing	15	0.38 (0.08) A	0.54 (0.06) B[b]
Post reconstruction – after fencing	21	0.35 (0.08) A	0.82 (0.09) A

[a] Passage rates differed among highway reconstruction classes (ANOVA $F_{2,44}$ = 3.33, P = 0.045)

[b] Passage rate for post reconstruction - before fencing class was less than the rate for during reconstruction (*P* = 0.042) and post reconstruction - after fencing (*P* = 0.014) classes

Comparison of Elk-Vehicle Collision Patterns

From 2002–2006, we documented 139 WVC that occurred along the CC section, 110 involving elk (79.1%) and 29 vehicle collisions with deer (20.9%). In both 2002 and 2003, 19 elk-vehicle collisions were recorded, with a large increase in 2004 to 52 collisions, of which 41 (78.8%) occurred in the 6 months after the section was opened to traffic but not fenced (fig. 5). Elk-vehicle collisions dropped to 12 in 2005 and 8 in 2006 after fencing. During 2002–2005, the proportion of total accidents that involved wildlife averaged 0.52 +/- 0.06); the proportion (0.76) increased 78.4% in the year after reconstruction was completed but before fencing was erected (2004), and then declined 30.3% in the year (2005) after fencing was erected to 0.55.

We found that differences in elk-vehicle collisions/season occurred among treatments ($F_{2,17}$ = 31.4, P < 0.001; table 4). The number of collisions during the period after the highway reconstruction was completed but before fencing (20.5 collisions/season) was higher than the mean number of collisions both during reconstruction (4.9 collisions/season) and after fencing (2.7 collisions/season; table 4). Of the elk-vehicle collisions that occurred in 2005 (12) and 2006 (8) since the CC section was fenced, 16 (80.0%) occurred where fencing was not erected, five (25%) occurred along the steep slope/elk rock treatment, and four (20%) where fencing was in place. Of the collisions that occurred along unfenced portions of the section, eight (50.0%) occurred in association with the 0.2-mi gap in the fence by the CC access road.

Table 3: Mean proportion of elk highway crossings along the Christopher Creek section, State Route 260, USA, before and after ungulate-proof fencing was erected and the mean proportion of change (Δ) with fencing. Letters denote significant differences for Tukey test pairwise passage deterrent class comparisons for significant ANOVA among classes

Highway passage deterrent class (*n* = no. of stretches)	Mean proportion of elk crossings		Mean in proportion of elk crossings[a] (SE)
	Before fencing	After fencing	
Ungulate-proof fencing (*n* = 3)	0.20	0.10	-0.10 (0.02) A
Steep slopes-"elk rock" (*n* = 1)	0.12	0.19	+0.07 - B
None (*n* = 4)	0.07	0.10	+0.03 (0.02) A,B

Wildlife Underpass Use Comparison

We recorded 500 elk and deer that approached the two UP from the camera side of the UP during the nine-month period prior to the erection of fencing. Of the 352 elk and deer that we categorized as attempting to cross the highway, a large proportion (0.60) avoided entering the UP altogether and crossed at grade over both sets of highway lanes in the vicinity of the UP. Another 74 elk and deer (0.21) were recorded making partial crossings under the first bridge at the UP and then crossing into the median and over one set of lanes. Overall, only 12% of the elk and deer successfully crossed below grade entirely through the UP prior to fencing. During the 11-month period after fencing was erected, we recorded 595 elk and deer that we determined were approaching the 2 UP, of which 331 successfully crossed (55.6%). We did not document any highway crossings at grade in the vicinity of the UP after fencing was erected.

The mean frequency of daily successful UP crossings by deer and elk increased 345.4% between the equivalent 9-month periods before ($\bar{x}$ = 0.66 +/- 0.06) and after ($\bar{x}$ = 2.94 +/- 0.20) fencing was erected on the CC Section (Mann-Whitney U-Test Us = 12.8, df =1, P < 0.001). Mean monthly successful elk and deer UP crossings increased over six fold between the nine-month period before ($\bar{x}$ = 11.5 ?0.08) and after ($\bar{x}$ = 65.4 +/- 3.87) fencing was erected (U_s = 12.8, df =1, P < 0.001).

The combined probability of an animal approaching either UP and successfully crossing was dependent on treatment, with an increase in probability from 0.09 to 0.56 following the erection of fencing (X^2 = 268.02, df = 1, P < 0.001, G^2 = 297.1, df =1, P < 0.001). The odds of and elk or deer successfully using the UP after fencing was 13.6:1 (95% CI: 9.6, 19.6) of that before fencing was erected. Considering the two UP separately, the probability of successful use of the Pedestrian/Wildlife UP by deer and elk increased from 0.19 to 0.67 following installation fencing (X^2 = 87.4, df = 1, P < 0.001, G^2 =92.6, df =1, P < 0.001), while the odds of them successfully using it after versus before fencing were 8.8:1 (95% CI: 5.5, 14.5). At the Wildlife 2 UP, the probability of successful wildlife use increased from 0.19 to 0.67 following fencing (X^2 = 177.5, df = 1, P < 0.001, G^2 =204.07, df =1, P < 0.001), and the odds of elk and deer successfully using this UP during the period after fencing versus before were 23.6:1 (95% CI: 13.6, 44.7).

Table 4. Mean collisions/season (2002–2006) by season and highway reconstruction class along the Christopher Creek section, State Route 260, Arizona, USA. Letters denote significant differences for Tukey test pairwise construction class comparisons for significant ANOVA among classes.

Season	Collisions per season (SE)	Highway reconstruction class (*n* = seasons)	Collisions per season[a] (SE)
Spring (Apr-Jun)	4.8 (0.9) A	During reconstruction (10)	4.9 (0.8) A
Summer (Jul-Sep)	6.7 (2.6) A	Post reconstruction - before fencing (2)	20.5 (5.5) B[b]
Fall (Oct-Dec)	9.8 (4.4) A	Post reconstruction - after fencing (8)	2.7 (1.2) A
Winter (Jan-Mar)	3.2 (0.7) A		

Discussion

We documented a benefit from ungulate-proof in reducing WVC comparable to that reported by Ward (1982) and Clevenger et al. (2001), with an 86.8% reduction in elk-vehicle collisions after fencing was erected. Further, our study points to the importance of fencing in funneling crossing wildlife toward and successfully through passage structures to maximize their effectiveness in promoting improved highway safety. Most surprisingly however, was the role that fencing played in promoting wildlife permeability in concert with increased use of UP and bridges along SR 260, heretofore undocumented by previous studies.

Prior GPS telemetry by Dodd et al. (2007b) provided an unprecedented opportunity to assess the degree to which highway reconstruction impacts wildlife permeability. The diminished passage rate reported for the CC Section, from 0.79 to 0.54 crossings/approach was consistent with the differential passage rates among highway reconstruction classes reported by Dodd et al. (2007b). They found that the rate for control sections averaged 0.88 compared to 0.43 on the section where reconstruction was complete; however, Dodd et al. (2007b) did not compare passage rates along the same section of highway in an experimental context as we did in this study. Dodd et al. (2007b) attributed the difference in passage rates among reconstruction classes to the combined influence of the increased highway footprint and presence of traffic on all lanes, effectively creating a large versus small road with high traffic volume, as described by Jaeger et al. (2005).

Numerous studies have alluded to the benefit of passage structures in maintaining or enhancing wildlife connectivity and permeability (e.g., Romin and Bissonette 1996, Clevenger and Waltho 2000, Forman et al. 2003). Our study provides some of most conclusive evidence to date to support the use of passage structures in restoring pre reconstruction levels of elk permeability. Our findings further point to the important dual role that fencing plays in not only achieving desired UP use by wildlife but in promoting permeability; in our case, both components were integral to fully mitigating the impact of highway reconstruction and reducing the incidence of WVC. We attribute the recovery in elk passage rate to pre reconstruction levels following fencing to the funneling of animals toward UP and bridges where they were presented below-grade opportunities for crossing that apparently ameliorated the road avoidance resistance to crossing a large roadway at grade (Jaeger et al. 2005) and traffic-associated impact reported by Gagnon (2006). Though Gagnon (2006) and Gagnon et al. (2007a) found that traffic volume affected elk distribution and crossing patterns at grade along SR 260, traffic volume had minimal affect on elk below-grade crossings through five wildlife UP along SR 260 (Gagnon 2006, Gagnon et al. 2007b), as illustrated in figure 6 from (Gagnon et al. 2007c).

We suspect that the success in promoting elk permeability with UP and fencing is partly attributable to the relatively high density of suitable passage structures along the CC section, though the degree to which spacing of structures contributed to permeability is uncertain. Bissonette (2006) applied allometric scaling principles to theorize on the spacing distance between passage structures to promote wildlife permeability. He reported that highest permeability would be attained where passage structure spacing is based on the species' linear home range distance; in the case of elk spacing was estimated at 3.5 km. On the CC section, our passage structures were spaced considerably closer with an average of 1.1 km between UP and bridges. Elsewhere on SR 260, ungulate-proof fencing was erected in late 2006 along 5 km of the Preacher Canyon (PC) section. Here the average passage structure spacing is 2.4 km, intermediate between that recommended by Bissonette (2006) and the spacing associated with our study. Permeability on the unfenced PC section averaged 0.43 crossings/approach (Dodd et al. 2007b), and post fencing elk GPS telemetry monitoring is ongoing to evaluate the change in permeability with fencing, and will yield considerable insights into the role of spacing distance between passage structures.

Our data underscore the important role that fencing plays in promoting wildlife use of passage structures, particularly those that are considered suboptimal. Gagnon et al. (2006) reported differential elk passage rates for the Pedestrian/wildlife (59%) and Wildlife 2 (27%) UP on the CC section, and hypothesized that the differential use was at least partly attributable to the degree of offset of bridges associated with each UP. At the Pedestrian/wildlife UP, the two bridges were constructed in line such that wildlife can see through the entire UP from any approaching angle. The Wildlife 2 UP was constructed with an offset along an existing drainage that ran diagonally to the highway, severely limiting visibility through the UP structure. With the erection of fencing, we noted a substantially greater benefit (e.g., >2.5× higher odds of successful crossings after fencing) achieved in "forcing" animals to use the Wildlife 2 versus the Pedestrian/wildlife UP. Such an approach to promoting wildlife passage through suboptimal passage structures or structures not specifically designed to accommodate wildlife passage has been reported by Singer and Doherty (1985) and Ng (2004). This may also be important where structures are not situated in proximity to preferred foraging areas or established travel corridors (Beier and Loe 1992, Bruinderink and Hazebroek 1996, Dodd et al 2007a). Though animals continually habituated to UP during the course of our study, we do not believe that this accounted for the dramatic increase in wildlife use of the two UP before and after fencing. As our UP were constructed and useable by wildlife well in advance (12 months) of the installation of our video camera systems, we believe that substantial wildlife exposure the UP had occurred in advance of our study, especially by elk which readily adapt to new UP (Clevenger and Waltho 2003, Dodd et al. 2007a).

Strategic fencing of peak elk crossing areas based on GPS telemetry (Dodd 2007b) accounting for only 49% of the CC section effectively mitigated the over three-fold increase in elk-vehicle collisions that occurred after the section was opened to traffic but before fencing was erected. Compared to the two years before the section was opened to traffic (2002-2003), the elk-vehicle collision rate for 2005-2006 declined 44.9%. However, once the 0.2-km gap at the entrance to Christopher Creek is fenced to eliminate elk crossings that account for half the collisions along the CC section, we expect the overall reduction in elk-vehicle collisions from before reconstruction levels to exceed 70%. Our application of steep slopes as an alternative to fencing did not prove effective in limiting at-grade elk crossings of SR 260.

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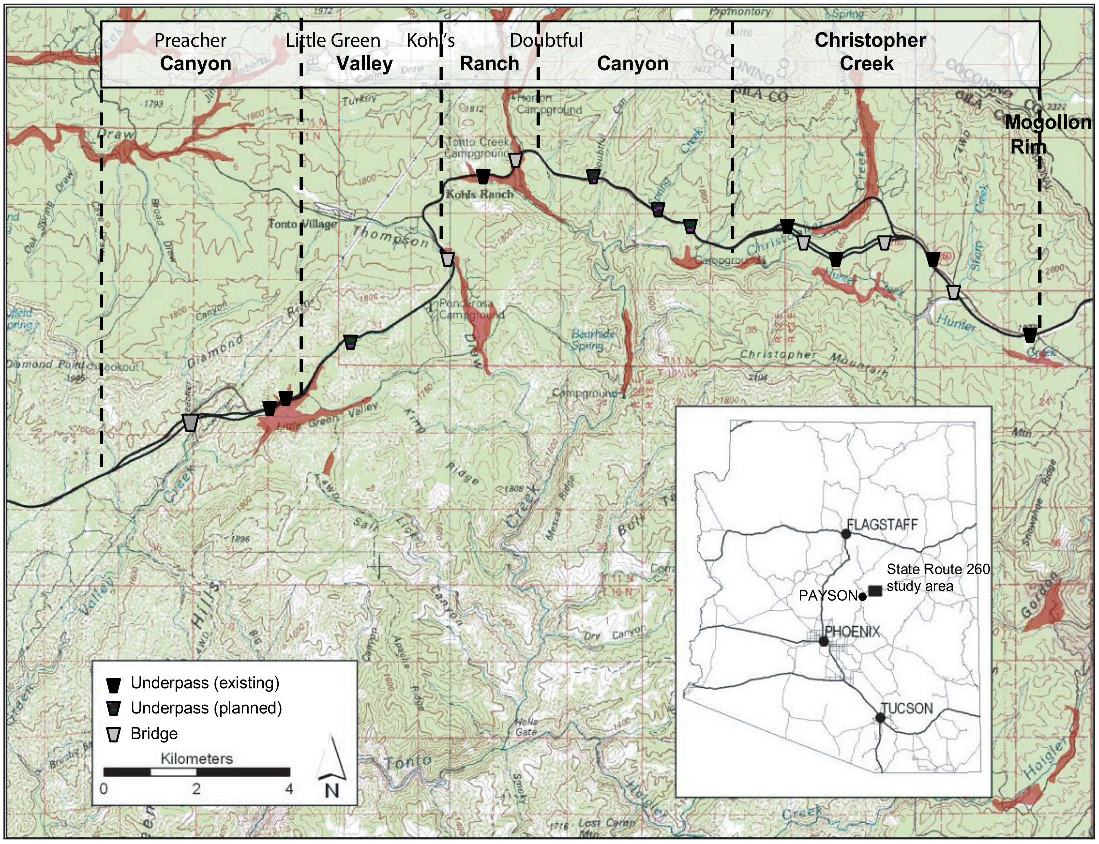

Figure 1. Location of our State Route 260 study area and the five highway sections along which phased highway reconstruction has been ongoing since 2000, and the location of wildlife UP and bridges. The shaded areas correspond to riparian-meadow habitats located adjacent to the highway. Topographic relief reveals the study area's proximity to the Mogollon Rim escarpment, the dominant physiographic feature within the study area.

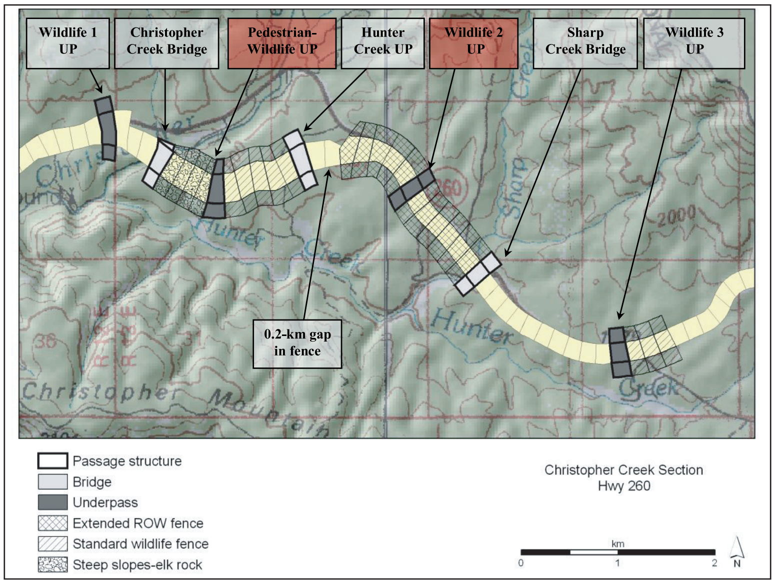

Figure 2. Location of wildlife underpasses (UP) and bridges along the Christopher Creek section of State Route 260, Arizona, USA, and delineation of different treatments to deter wildlife passage onto the highway and funnel animals toward passage structures. Also identified is the 0.2-km gap in the fence at the east entrance into Christopher Creek and the 2 UP where before and after fencing video surveillance was conducted (shaded red).

Figure 3. Alternatives to fencing to deter at-grade wildlife crossings along the Christopher Creek section of State Route 260, Arizona, USA. The steep 4:1 fill slopes below guard rails (left), boulder rip-rap ("elk-rock") and steep cut slopes (right) were evaluated as alternative treatments to fencing.

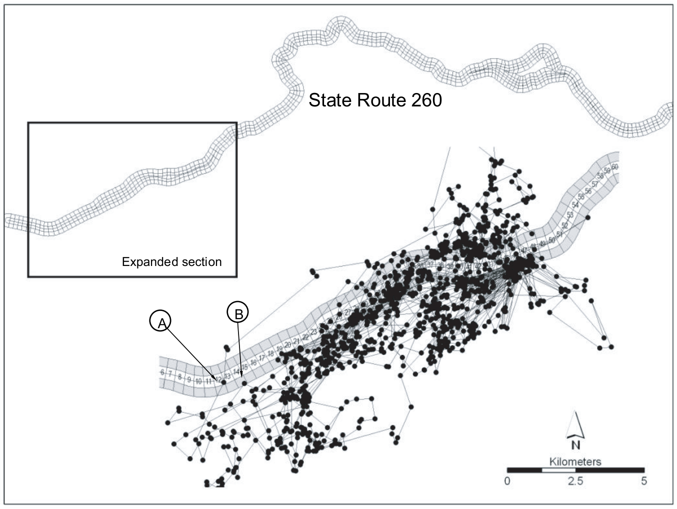

Figure 4. Highway segments (0.16 km) delineated along State Route 260, Arizona, USA, used to compile highway crossings by elk, and the 0.25-km distance buffer in which approaches to the highway were determined. The expanded section shows GPS locations for cow elk no. 2, and lines between successive fixes to determine approaches to the highway (shaded band) and crossings. Example A denotes an approach and subsequent highway crossing, while B denotes an approach without a crossing.

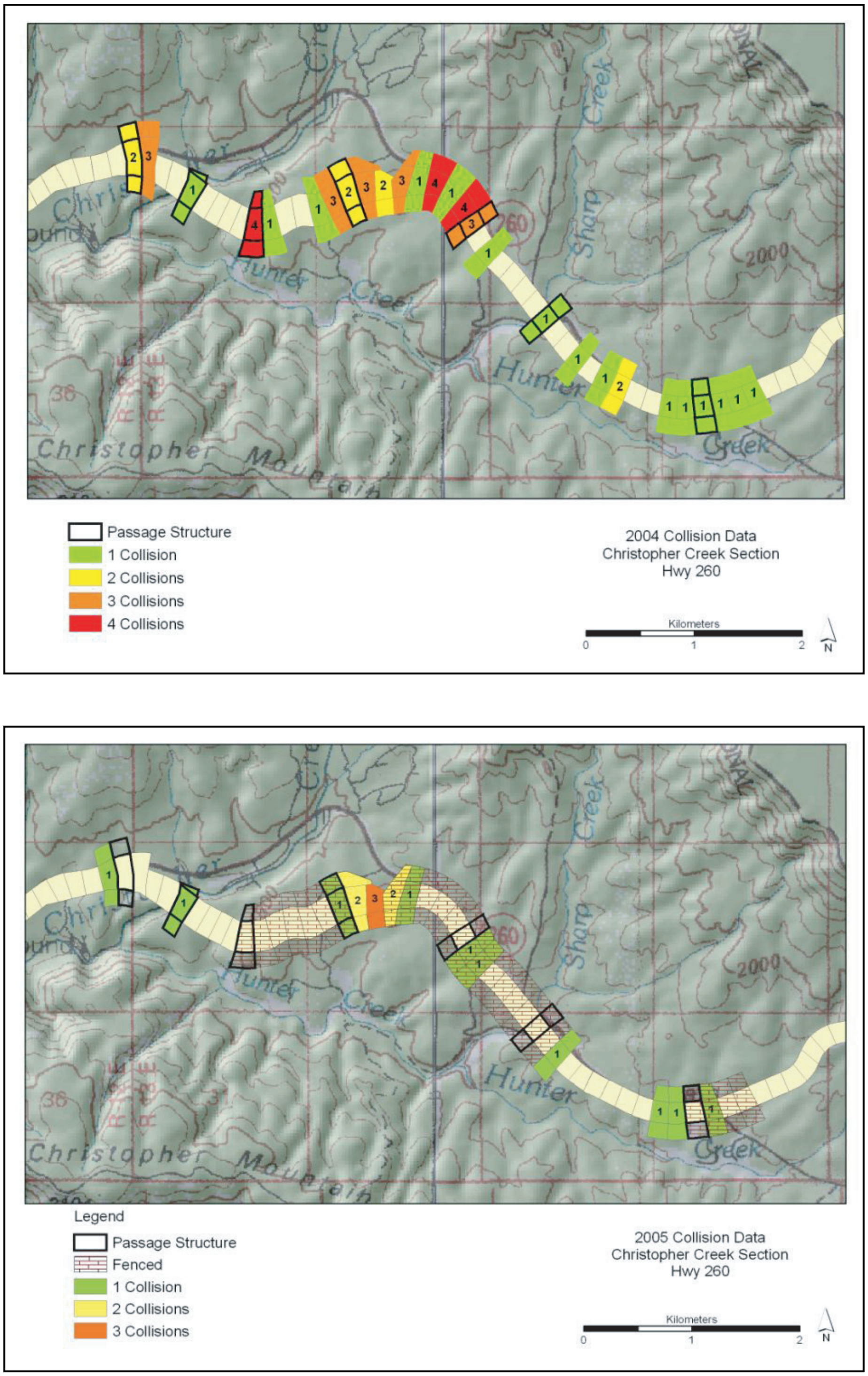

Figure 5. Number of elk-vehicle collisions recorded along the Christopher Creek section of State Route 260, Arizona, USA in 2004 (top; 51 collisions) before ungulate-proof fencing was erected and 2005 (bottom; 12 collisions) after fencing was erected. Note the concentration of collisions in 2005 at the 0.2-km gap in the fence near the entrance to Christopher Creek.

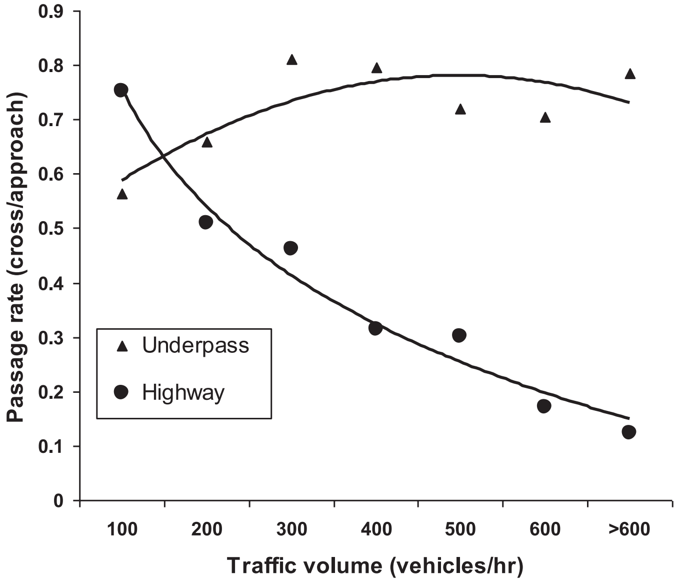

Figure 6. At-grade and below-grade (through 6 wildlife underpass) elk passage rates at varying traffic volume levels along State Route 260, Arizona, USA (figure from Gagnon et al. 2007c). At-grade passage rates determined from GPS telemetry tracking of 44 elk from 2003-2006 (Gagnon et al. 2007a) and below-grade underpass passage rates determined from video surveillance of wildlife use of underpasses from 2002-2006 (Gagnon et al. 2007b).