EVALUATION OF MEASURES TO MINIMIZE WILDLIFE-VEHICLE COLLISIONS AND MAINTAIN PERMEABILITY ACROSS HIGHWAYS:

Arizona Route 260

Final Report 540

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16. Abstract

We conducted wildlife-highway relationships research from 2002–2006 along a 17-mile stretch of State Route 260 in Arizona which is being reconstructed in five phases with 11 wildlife underpasses and 6 bridges. Reconstruction phasing allowed us to use a before-after-control experimental approach in our research. The objectives of our research were;

1) Assess and compare wildlife use of underpasses. 2) Evaluate highway permeability and wildlife movements among reconstruction classes. 3) Characterize wildlife-vehicle collision patterns and changes with reconstruction. 4) Assess relationships among highway traffic volume and wildlife vehicle collisions, elk crossing patterns, and wildlife use of underpasses. 5) Assess the role that ungulate-proof fencing plays in wildlife vehicle collisions, wildlife use of underpasses, and wildlife permeability. 6) Provide ongoing highway reconstruction implementation guidance.

We used video surveillance to assess and compare wildlife use of five underpasses at which we recorded 8,455 animals and 11 different species; 5,560 of these animals (65.8%) crossed through the underpass. We employed Global Positioning System telemetry to assess highway permeability across SR 260, with 65 elk fitted with receiver collars. Elk crossed State Route 260 5,749 times. Elk permeability on reconstructed highway (0.43 crossings/approach) was half that of control sections. Permeability increased 60% after ungulate-proof fencing was erected on a reconstructed section. Effective monitoring and adaptive management yielded benefits to highway safety and wildlife permeability alike.

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SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	Square inches	645.2	square millimeters	mm^2	mm^2	square millimeters	0.0016	square inches	in^2
ft^2	square feet	0.093	square meters	m^2	m^2	square meters	10.764	square feet	ft^2
yd^2	square yards	0.836	square meters	m^2	m^2	square meters	1.195	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	square kilometers	km^2	km^2	square kilometers	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	Cubic feet	0.028	cubic meters	m^3	m^3	cubic meters	35.315	cubic feet	ft^3
yd^3	Cubic yards	0.765	cubic meters	m^3	m^3	cubic meters	1.308	cubic yards	yd^3
NOTE: Volumes greater than 1000L shall be shown in m^3.									
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	megagrams (or “metric ton”)	mg (or “t”)	mg (or “t”)	megagrams (or “metric ton”)	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION					**ILLUMINATION**		
fc	foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS					**FORCE AND PRESSURE OR STRESS**		
lbf	poundforce	4.45	Newtons	N	N	Newtons	0.225	poundforce	lbf
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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Javelina	*Tayassu tajacu*
Moose	*Alces alces*
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Mountain lion	*Puma concolor*
Mule deer	*Odocoileus hemionus*
Pronghorn	*Antilocapra americana*
Rocky Mountain elk	*Cervus elaphus nelsoni*
White-tailed deer	*Odocoileus virginianus cousei*
Wolf	*Canis lupus*

Plants

Douglas fir	*Pseudotsuga menzeisii*
Gambel oak	*Quercus gambelii*
Juniper	*Juniperus spp.*
Manzanita	*Arctostaphalos pungens*
Pinyon	*Pinus edulis*
Ponderosa pine	*Pinus ponderosa*
White fir	*Abies concolor*

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The ATRC's Technical Advisory Committee for this project provided many suggestions toward improving its effectiveness and applicability. Their tremendous support, oversight, and commitment throughout the duration of the project were greatly appreciated.

1.0 EXECUTIVE SUMMARY

We studied wildlife-highway relationships from 2002–2006 along a 17-mi stretch of State Route (SR) 260, in central Arizona, USA. This stretch is being reconstructed from a two-lane to a four-lane divided highway in five phases incorporating 11 wildlife underpasses and six bridges. Phased reconstruction allowed us to use a before-after-control experimental approach in our research. The objectives of our research were to:

- Assess and compare wildlife use of underpasses.
- Evaluate highway permeability and wildlife movements among reconstruction classes.
- Characterize wildlife-vehicle collision patterns and changes with reconstruction.
- Assess relationships among highway traffic volume and wildlife-vehicle collisions, elk crossing patterns, and wildlife use of underpasses.
- Assess the role that ungulate-proof fencing plays in wildlife-vehicle collisions, wildlife use of underpasses, and highway permeability to wildlife.
- Provide ongoing highway reconstruction implementation guidance.

We used video camera surveillance to assess and compare wildlife use of five underpasses. We recorded 8,455 animals and 11 different species; 5,560 of these animals (65.8%) crossed through the underpasses. Our underpass passage rates ranged from 0.10–0.68 crossing/approach, and underpass structure and placement was the most important factor of five modeled influencing the probability of successful underpass crossing by elk (*Cervus elaphus nelsoni*). We used Global Positioning System (GPS) telemetry data collected from 65 elk fitted with GPS receiver collars to assess movement patterns and highway permeability. Our elk crossed SR 260 5,749 times. Elk permeability on reconstructed highway (0.43 crossings/approach) was half that of the control sections. Permeability increased 60% after ungulate-proof fencing was erected on a reconstructed section, linking underpasses. Fencing also resulted in >80% reduction in elk-vehicle collisions and improved underpass effectiveness as elk and deer (*Odocoileus* spp.) underpass passage rates increased from 0.12 to 0.56 crossings/approach after fencing. While we found that traffic volume did affect elk highway crossing and distribution patterns at highway grade, it had little or no impact on elk crossing below grade through underpasses. We assessed spatial and temporal patterns of elk-vehicle collisions (n = 571). Annual elk-vehicle collisions were related to traffic volume and elk population levels. Mean elk-vehicle collisions during reconstruction (11.6/year) was higher than before (4.4/year) and after reconstruction (6.5/year) for each section. The benefit of reduced elk-vehicle collisions from underpasses and fencing was projected to approach $1 million/year. We compared elk-vehicle collisions and elk GPS crossings at five scales and found that the strength of the relationship and management utility were optimized at the 0.6-mi scale. The proximity of riparian-meadow habitats and permanent water along SR 260 influenced the pattern of elk GPS crossings and elk-vehicle collisions. Together, effective monitoring and adaptive management improved both highway safety and highway permeability to wildlife.

We report our research findings in eight separate chapters or volumes addressing various aspects of our research. A summary for each volume follows below, as well as an overall summary of project conclusions and recommendations.

1.1 VIDEO SURVEILLANCE TO ASSESS HIGHWAY UNDERPASS USE BY ELK

We used integrated video systems to compare wildlife use of two bridged wildlife underpasses on the Preacher Canyon section from September 2002–September 2005. Both underpasses opened into the same riparian-meadow complex, were situated <850 ft apart, and had different below-span characteristics and dimensions. Our objectives were to compare elk response to the underpasses and test hypotheses that passage rate, probability of use, and behavioral response at the two underpasses did not differ. We related differences in elk use and response to underpass design characteristics. Elk accounted for >90% of the animals we recorded on videotape, with 3,708 elk in 1,266 groups recorded at the two underpasses. We used multiple logistic regression to predict the probability of underpass use by elk incorporating the combined effects of underpass, season, and year. Season had the greatest effect on underpass use, with the probability of underpass use in summer (0.81) higher than winter (0.58) when migratory elk less habituated to the underpasses were present. A pattern of high summer (>0.80) and low winter passage rates (<0.40), regardless of underpass, existed in all three years of video surveillance. Underpass design characteristics also had an effect on the probability of elk crossing the underpass; the probability of use of the underpass with two times the openness ratio, half the length for elk to traverse, and sloped earthen sides (0.75) was higher than the neighboring underpass with concrete walls (0.66). Proportions of elk displaying behaviors indicative of resistance to crossing were dependent on underpass and were higher at the underpass with concrete walls. In all cases, elk preferred the more open underpass with natural earthen sides. We believe that differences in underpass length and the concrete walls contributed to differences in elk use and behavioral response. Continued video surveillance of these and other underpasses will allow us to evaluate their efficacy in promoting wildlife permeability.

1.2 EFFECTS OF TRAFFIC VOLUME ON ELK USE OF WILDLIFE HIGHWAY UNDERPASSES

Structures that allow wildlife to cross the highway corridor are increasingly used to mitigate potential negative impacts of roadways, but little is known about how varying traffic levels may limit their effectiveness, either by reducing wildlife passage rates or by causing animals to cross highways at other locations where they could potentially cause collisions. We monitored five wildlife crossings SR 260 using video surveillance to determine if traffic levels or traffic types (semi-trailer truck versus automobile) affected elk use of wildlife underpasses. We examined elk crossing behavior at wildlife underpasses at two critical points during the crossing period: 1) when elk initially approached the underpass, and 2) after elk entered the underpass. Passage rates at low, intermittent traffic volume (0-2 vehicles/min = 0.59, 2-4 vehicles/min = 0.75) and at higher traffic levels (4-6 vehicles/min = 0.73, >6 vehicles/min = 0.71) were not markedly reduced compared to passage rates when no vehicles were present (0.65). Passage rates varied seasonally, likely due to the presence of migratory elk unused to underpasses during part of the year, but even during migratory periods traffic level had minimal effect on the passage rate. Thus, increasing traffic did not substantially reduce the effectiveness of wildlife underpasses as viable means of mitigating wildlife population fragmentation, at least at the traffic levels we studied. Semis were five times more likely than were passenger vehicles to cause a flight behavior when traffic levels were intermittent versus when traffic was continuous, possibly due to the sudden increase in sound and vibration. If flight away from underpasses causes animals to cross the highway at other points and thereby increase the potential for elk-vehicle collisions, measures that reduce traffic noise and visual stimuli caused by passing vehicles at underpasses may be warranted.

1.3 ASSESSMENT OF ELK HIGHWAY PERMEABILITY USING GLOBAL POSITIONING SYSTEM TELEMETRY

Highways have significant direct and indirect impact to natural ecosystems, including wildlife barrier and fragmentation effects, resulting in diminished habitat connectivity and highway permeability. We used GPS telemetry to assess elk movement patterns and permeability across SR 260. The highway was reconstructed in phases, allowing for comparison of highway crossing and passage rates during various stages of reconstruction. We instrumented 33 elk (25 female, 8 male) with GPS receiver collars May 2002-April 2004. Our collars accrued 101,506 GPS fixes with 45% occurring within 0.6 mi of the highway. Nearly two times the proportion of locations occurred within 0.6 mi of the highway compared to randomly generated locations. We believe elk were attracted to the highway corridor by riparian-meadow foraging habitats that were seven times more concentrated within the 0.6-mi zone around the highway compared to the mean proportion within elk use areas encompassing all GPS fixes. Elk crossed the highway 3,057 times; crossing frequency and distribution along the highway was aggregated compared to random. Crossing frequency within 0.1-mi highway segments was negatively associated with the distance to riparian-meadow habitats. Mean observed crossing frequency (92.6 crossings/elk) was lower than random (149.6 crossings/elk). Cows crossed 4.5× as frequently as bulls. Highway permeability among reconstruction classes was assessed using passage rates (ratio of highway crossings to approaches); our overall mean passage rate was 0.67 crossings/approach. The mean passage rate for elk crossing the highway section where reconstruction was completed (0.43 crossings/approach) was half that of sections under reconstruction and control sections combined (0.86 crossings/approach). Permeability was jointly influenced by the size of the widened highway and associated vehicular traffic on all lanes. Crossing frequency was used to delineate where ungulate-proof fencing yielded maximum benefit in intercepting and funneling crossing elk toward underpasses and reducing elk-vehicle collisions. Use of passage rates provides a quantitative measure to assess highway permeability, conduct future before and after construction comparisons, and develop mitigation strategies to minimize the impact of highways on wildlife.

1.4 ROLE OF FENCING IN PROMOTING WILDLIFE UNDERPASS USE AND HIGHWAY PERMEABILITY

Ungulate-proof fencing has been used successfully to mitigate the incidence of wildlife-vehicle collisions on highways throughout North America. 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. The five-mile reconstructed Christopher Creek section was opened to traffic six months before ungulate-proof fencing was erected, linking four wildlife underpasses and three bridges. To assess the role of strategically placed fencing along 49% of the section, we compared before and after fencing elk-vehicle collision incidence, wildlife use of underpasses, 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 underpasses to compare wildlife use for nine months before and 11 months after fencing was erected. Before fencing, we recorded 500 elk and deer at the underpasses, of which only 12% successfully passed through the underpasses; 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 underpass increased from 0.09 to 0.56 with fencing, and the combined odds of a crossing through the underpass after fencing was 13.6:1 compared to before fencing. We used 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 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 (one structure/0.7 mi) promoted elk highway permeability by funneling animals toward the underpass where resistance to crossing was lower than that associated with crossings at grade.

1.5 INFLUENCE OF FLUCTUATING TRAFFIC VOLUME ON ELK DISTRIBUTION AND HIGHWAY CROSSINGS

We linked 38,709 GPS locations collected from December 2003–June 2006 from 44 elk fitted with GPS collars and hourly SR 260 traffic data, totaling more than 6,470,000 vehicles to determine how elk distribution varied with traffic volume, and how traffic volume related to highway crossings. The probability of elk occurring near the highway decreased with increasing traffic volume, indicating that habitat near the highway was used by elk, but primarily when traffic volumes were relatively low (<100 vehicles/hr). We used multiple logistic regression combined with Akaike's Information Criteria to identify factors potentially important in influencing probability of elk crossing the highway. We found that increasing traffic volume reduced the overall probability of highway crossing, but this effect depended on both season and the proximity of riparian-meadow habitat, with elk crossing highways at higher traffic volumes during spring and fall migratory periods and when accessing these riparian-meadow foraging areas. Overall, our results indicate that: 1) fluctuations in traffic volume should be considered in models of habitat effectiveness for elk, 2) the effect of traffic volume on probability of highway crossing, and therefore highway permeability, will depend on how a highway affects access to daily and seasonally important resources, and 3) increased traffic volume alone will not prevent elk from crossing the roadway and therefore development of effective wildlife passages or motorist warning signs could reduce the probability of elk-vehicle collisions, especially during migratory periods if placed near riparian-meadow habitat or other areas with preferred resources.

1.6 CHARACTERISTICS OF ELK-VEHICLE COLLISIONS AND COMPARISON TO HIGHWAY CROSSING PATTERNS

We assessed spatial and temporal patterns of elk-vehicle collisions from 1994-2006 (n = 571) along SR 260. We used GPS telemetry to assess spatial and temporal patterns of elk highway crossings and compare to elk-vehicle collisions patterns. Annual elk-vehicle collisions were related to traffic volume and elk population levels. elk-vehicle collisions occurred in a non-random pattern. With three of the sections completed, mean elk-vehicle collisions while they were under reconstruction (up until ungulate-proof fencing was erected; 11.6/year) was higher than mean before-construction elk-vehicle collisions (4.4/year) and after reconstruction (6.5/year) elk-vehicle collisions for each section. On the first section completed in 2001 with limited fencing (13%), elk-vehicle collisions did not differ among before, during, and after construction classes, even though mean traffic volume increased 67% from before- to after-construction levels, pointing to the benefit of three passage structures and fencing. On another section completed in 2004, elk-vehicle collisions increased >2.5× when opened to traffic but before fencing was erected; elk-vehicle collisions dropped >70% once fencing was installed. The benefit associated with reduced elk-vehicle collisions from underpass and fencing was projected to approach $1 million/year. We accrued 101,506 fixes from 33 elk (25 females, 8 males) fitted with GPS collars 2002-2004. Elk crossed the highway 3,057 times in a non-random pattern. We compared elk-vehicle collisions and crossings at five scales; the strongest relationship was at the highway section scale. Strength of the relationship and management utility were optimized at the 0.6-mi scale. Elk-vehicle collision frequency was associated with proximity to riparian-meadow habitats adjacent to the highway at the section and 0.6-mi scales. Though both fall elk-vehicle collisions and crossings exceeded expected levels, the proportion of elk-vehicle collisions 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.

There was no difference in the proportion of elk-vehicle collisions and crossings by day, as both reflected avoidance of crossing the highway during periods of highest traffic volume. Though traffic volume was highest from Thursday-Saturday, the proportion of elk-vehicle collisions was lower than expected. A higher proportion of elk-vehicle collisions (59%) occurred relative to crossings (33%) in the evening (1700-2300 hr); 34% of elk-vehicle collisions occurred within a one-hour departure of sunset, and 55.5% within a two-hour departure. Elk-vehicle collision data are valuable in developing strategies to maintain permeability and increase highway safety including selecting locations of passage structures.

1.7 INFLUENCE OF ENVIRONMENTAL FACTORS ON ELK HIGHWAY CROSSINGS

Vehicle collisions with ungulates are recognized as a serious problem because they threaten human safety and cause tremendous property damage, as well as impact wildlife populations. Such risks to humans and wildlife make it important to understand how environmental factors influence ungulates highway crossing patterns. Several studies have described site-specific variables at ungulate-vehicle accident sites, but none have used highway crossing data. Also, previous studies lack information on how riparian-meadow habitats influence road crossings. We used GPS data from 33 elk collared from 2002–2004 to determine where they crossed SR 260. Our GPS collars yielded more than 101,000 GPS fixes from which we determined 3,057 crossings of the highway. We delineated 90 0.2-mi segments along a 17-mi stretch of the highway and calculated weighted elk crossings associated with each segment. We selected the 20 0.2-mi segments that exhibited the highest and the 20 with the lowest weighted elk crossing frequencies, and measured various habitat factors associated with these segments. To assess the influence of habitat factors on elk highway crossing patterns, we conducted field validations and Geographic Information System analysis to model five environmental parameters: 1) proximity to nearest meadow, 2) proximity to nearest permanent water source, 3) forest canopy, 4) slope, and 5) aspect. We employed a Classification and Regression Tree (CART) approach to determine the hierarchical order of importance for each variable tested for both our high and low frequency elk highway crossing segments. Proximity to water and meadow were tied for most influential factors associated with high frequency weighted crossing sites. The CART-derived classification tree indicated that water occurred less than 2,500 ft from all high crossing segments, and meadow occurred less than 3,100 ft from 85% of the high crossing sites. The results from this study provide important information that can be used to mitigate the incidence of wildlife-vehicle collisions and design safe and ecologically sensitive highways.

1.8 PRELIMINARY ASSESSMENT OF FACTORS INFLUENCING WILDLIFE USE OF HIGHWAY UNDERPASSES

We assessed and compared wildlife use of five underpasses on the Preacher Canyon and Christopher Creek sections of SR 260, using data from video camera surveillance conducted 2002–2006. Our video surveillance systems were designed to capture animals approaching and crossing though the underpasses, allowing us to measure passage rates (crossings/approach). We recorded 8,455 animals and 11 different species on 1,100 hours of videotape. Overall, 5,560 of these animals, or 65.8%, crossed through the underpasses. Elk accounted for the majority of the animals documented at the underpasses (73.8%), while white-tailed deer and mule deer accounted for 10.9% and 7.4% of the total, respectively. Our mean elk underpass passage rates ranged from 0.10–0.68 crossing/approach for the five monitored underpasses. We used multiple logistic regression to select factors important in predicting probability of a successful crossing through the underpasses by elk; we modeled the influence of underpass (structure and placement), season, length of monitoring, time of day, and day of the week. We used a general linear model with a logit link to determine probabilities of a successful crossing for each of the factors selected. We found that four factors were important in predicting the probability of a successful crossing once elk approached the underpass. Our underpass factor was the most important one, suggesting that underpass structure and placement was of primary importance in predicting the probability of successful elk passage at the underpass, with probabilities of successful elk crossing ranging from 0.09–0.77. The length of time an underpass was monitored was the second most important factor selected in our logistic regression modeling (with the probability of successful crossing increasing from 0.52 in the first year of monitoring to 0.69–0.71 in the subsequent four years), followed closely by season and time of day. The probability of successful elk crossing during fall, when migratory elk not habituated to our underpasses were present along SR 260 was 0.59 compared to 0.71 during summer. Day of the week, our surrogate factor for traffic volume did not have a significant influence on crossing probabilities at our below grade passage structures.

1.9 OVERALL CONCLUSIONS AND RECOMMENDATIONS

Our research underscored the ability to integrate transportation and ecological objectives into highway construction activities, yielding tangible benefits to both highway safety and wildlife permeability. The combination of phased construction, adaptive management, and effective monitoring of measures to reduce wildlife-vehicle collisions and promote permeability were instrumental to achieving transportation and ecological objectives. We recommend that such an approach to highway construction and monitoring be pursued elsewhere in the state whenever possible. In the instance of SR 260, ADOT prioritized the reconstruction of the five sections on the historic incidence of wildlife-vehicle collisions. Our research validated this prioritization; the strong association between elk-vehicle collisions and highway crossings underscored the utility and value of wildlife-vehicle collision data in planning wildlife mitigation measures ranging from passage structures to ungulate-proof fencing. We strongly recommend that all work units within ADOT and other agencies make a concerted effort to collect and archive wildlife-vehicle collision data throughout Arizona, utilizing the standardized interagency collision report form.

We found that the presence of riparian and wet meadow habitats constituted the “engine” that drove conflicts between the highway and wildlife along SR 260. Elk-vehicle collision and elk highway crossing patterns were closely associated with proximity to riparian-meadow habitats. Future highway construction activities should avoid such limited, valuable habitats where possible. Wildlife underpasses located adjacent to riparian-meadow habitats received high levels of use by wildlife due to their movement toward these preferred foraging areas, as well as animal propensity to travel along drainages. Where highway alignments near riparian-meadow habitat are unavoidable, such sites are excellent locations to consider wildlife passage structures.

Wildlife underpasses were highly effective in promoting below-grade wildlife crossings, with two-thirds of over 8,500 animals recorded during video surveillance having crossed through an underpass. These underpasses were instrumental to improving highway safety through reduction of wildlife-vehicle collisions and promoting wildlife permeability. Structural design characteristics and placement of underpasses are important considerations to maximizing their efficacy in promoting wildlife passage, and structural characteristics were the most important factor in determining the probability of successful crossings by wildlife. Underpass openness is crucial to achieving high probability of successful underpass use. The distance that animals must travel through an underpass is an especially important factor in maximizing efficacy, and should be minimized in underpass design. Elk avoided an underpass where concrete mechanically stabilized earth walls were erected for soil stabilization, compared to a neighboring underpass with more natural 2:1 sloped earthen sides. We recommend that the application of concrete walls be avoided in wildlife underpasses. Visibility through underpasses should be maximized during design and implementation. Where underpasses occur on divided highways we recommend that the bridges be placed in line where possible to maximize visibility by animals through the structures. Wildlife underpass placement should avoid areas of high human activity or congregation that occur outside daytime hours.

We documented a recurring seasonal pattern where elk underpass passage rates dropped from summer levels >0.90 crossings/approach to below 0.40 during the fall when migratory elk moved through the SR 260 corridor. Migratory elk do not appear to exhibit the same propensity for habituation to underpasses as resident elk. Additional ungulate-proof fencing may be needed to address this seasonal drop in underpass passage rates. Long term monitoring will provide valuable insights on changes in wildlife use patterns. Ungulate-proof fencing in conjunction with underpasses will expedite the wildlife learning process.

Traffic levels fluctuated greatly on an hourly, daily and seasonal basis through our study area, averaging between 7,000–8,500 average annual daily traffic (AADT). We found that traffic volume influenced elk crossing patterns and distribution at highway grade. With increasing traffic levels, we found reduced probability of successful elk highway crossings at grade, crossings occurred later in the evening when volume levels abated, and elk moved away from the highway as volumes increased. Unsuccessful attempts to cross SR 260, or "repels" typically coincided with high traffic volume. Conversely, at our monitored wildlife underpasses, traffic volume on SR 260 overhead did not have an effect on elk approaching and successfully crossing through the underpasses below grade. This finding was of paramount importance to understanding the efficacy of underpasses in promoting wildlife permeability.

GPS telemetry afforded us an unprecedented opportunity to assess and compare wildlife permeability among highway reconstruction classes, as well as assess permeability before and after the erection of ungulate-proof fencing. Reconstruction from a two-lane to four-lane divided highway reduced wildlife permeability by half compared to that of our control sections. On one section, the during reconstruction passage rate dropped 34% after reconstruction but before fencing was erected. Yet the elk passage rate increased 54% after half of the section was strategically fenced with ungulate-proof fencing. Thus, fencing in conjunction with underpasses promoted wildlife permeability as animals were funneled toward underpasses and bridges where they crossed below grade with minimal impact from traffic passing above. In addition to playing an instrumental role in promoting permeability, ungulate-proof fencing was crucial to achieving effective use of underpasses, especially those not located in proximity to meadow habitats. Without fencing, elk and deer continued to cross SR 260 at grade immediately adjacent to underpasses. The 50% of the section that was fenced was projected to intercept 89% of elk crossings determined from GPS telemetry, and yielded an 83% reduction in elk-vehicle collisions in the year after fencing. Fencing is an integral component of wildlife mitigation measures in reducing elk-vehicle collisions and promoting wildlife permeability.

With two of the five SR 260 sections reconstructed to date integrating underpass and ungulate-proof fencing, 2006 was the first year that the incidence of actual elk-vehicle collisions dropped below the level predicted from modeling based on average annual daily traffic (AADT) volume and elk population levels. Our model predicted even greater benefit as AADT increases. Thus, the complement of measures implemented to date has achieved its objective in mitigating the impact of highway reconstruction and increasing traffic volume, and the benefit is expected to grow now that the third section is complete (Kohl's Ranch) and the entire Preacher Canyon section is being fenced under an enhancement grant project. With only a modest increase in AADT, we estimated an annual benefit from reduced elk-vehicle collisions of nearly $1 million/year.

Compared to the first three reconstructed sections, the remaining two exhibited relatively few wildlife-vehicle collisions or collared elk crossings. The exception is the limited areas where riparian-meadow habitat is located in close proximity to the highway.

2.0 INTRODUCTION

2.1 BACKGROUND

Highways directly and indirectly create some of the most prevalent and widespread changes to the ecosystem in the United States (Noss and Cooperrider 1994, Trombulak and Frissell 2000, Farrell et al. 2002). The estimated 500,000 to 700,000 deer killed each year in collisions on U.S. highways directly affect the ecosystem (Romin and Bissonette 1996*a*, Schwabe and Schuhmann 2002). Collisions also cause human injuries, deaths, and tremendous property loss (Reed et al. 1982, Schwabe and Schuhmann 2002), and disproportionately affect threatened or endangered species (Foster and Humphrey 1996).

Highways indirectly impact ecosystems by causing habitat loss and blocking animal movements. Forman and Alexander (1998) estimated that highways have caused habitat loss and degradation in more than 20% of the U.S. Blocking of animal movements between seasonal ranges or other vital habitats is perhaps highways' most pervasive environmental impact. (Noss and Cooperrider 1994, Forman and Alexander 1998, Forman 2000). Their fragmentation of habitats and populations reduces genetic interchange (Gerlach and Musolf 2002) and limits dispersal of young (Beier 1995); all serving to disrupt viable wildlife population processes. Long-term fragmentation and isolation renders populations more vulnerable to catastrophic events and may lead to extinctions (Hanski and Gilpin 1997). Fencing to prevent wildlife and livestock access to highways may exacerbate the barrier effect unless provision is made for passage.

Though numerous studies have alluded to highways' barrier effects on wildlife (e.g., see Forman et al. 2003), few have yielded quantitative data on animal passage rates, particularly in an experimental context (e.g., pre- and post-highway construction). Many studies have focused on the efficacy of passage structures at allowing wildlife to avoid at-grade crossings (Clevenger and Waltho 2003, Ng et al. 2004) or have relied on modeling to assess highways' passability, or permeability to wildlife (Singleton et al. 2002). Assessments of the habitat fragmentation highways cause for relatively low-mobility small mammals have yielded quantifiable results from mark-recapture trapping, but assessments for larger, far-ranging species have been limited by cost (Swihart and Slade 1984, Conrey and Mills 2001, McGregor et al. 2003). Paquet and Callaghan (1996) used winter track counts adjacent to highways and other barriers to determine passage rates by wolves (*Canis lupus*), something few other studies have reported. VHF radio telemetry has also been used to assess wildlife movements and responses to highways, often pointing to avoidance of highways and roads (Brody and Pelton 1989, Rowland et al. 2000), but seldom directly addressing permeability as Gibeau et al. (2001) did for grizzly bears (*Ursus arctos*).

Numerous studies have been conducted on the spatial and temporal patterns of wildlife-vehicle collisions, most focusing on deer (Reed and Woodard 1981, Bashore et al. 1985, Romin and Bissonette 1996*b*, Hubbard 2000). Only recently have researchers specifically addressed patterns of collisions with elk (*Cervus elaphus*) (Gunson and Clevenger 2003, Biggs et al. 2004). Insights gained from such studies have been instrumental in developing strategies to reduce collisions with wildlife (Romin and Bissonette 1996*a*, Farrell et al. 2002), including planning passage structures to reduce at-grade crossings and maintain passage (Clevenger et al. 2002).

Consistent tracking of wildlife-vehicle collisions is a valuable tool to assess the impact of highway construction on wildlife (Romin and Bissonette 1996*b*) and the efficacy of passage structures and other measures (e.g., fencing) in reducing wildlife-vehicle collisions (Reed and Woodard 1981, Ward 1982, Clevenger et al. 2001a). Though data on wildlife-vehicle collisions is valuable, no study has investigated or validated the relationships between these collisions and the spatial and temporal crossing patterns of the wildlife involved. In fact, Barnum (2003) reported that these data were not useful in identifying crossing zones, largely due to inaccurate reporting.

Underpasses, overpasses and other structures designed to promote safe passage of large animals across highways are being built more frequently throughout North America (Clevenger and Waltho 2000). Whereas early passage structures were typically designed to mitigate the impact on a single-species (Reed et al. 1975), the focus today is more on preserving ecosystem integrity and landscape continuity to benefit multiple species (Clevenger and Waltho 2000). Transportation agencies increasingly are receptive to integrating passage structures into highways to address both safety and ecological needs (Farrell et al. 2002). However, they increasingly expect that such structures will benefit multiple species and enhance access to habitat (Clevenger and Waltho 2000); and that scientifically sound monitoring and evaluation of wildlife response will be done to improve future effectiveness (Clevenger and Waltho 2003, Hardy et al. 2003).

Just as varied approaches have been used to assess wildlife passage, a multitude of methods measures have been used to measure wildlife use of passage structures. Most studies' data have come from underpass track counts (Clevenger and Waltho 2000, Gloyne and Clevenger 2001), event recorders (Foster and Humphrey 1995), or single-frame camera images (Ng et al. 2004). Using frequency-of-use data to compare passage structure use has a potential bias due to heterogeneous animal distribution or the differential funneling caused by varying amounts of wildlife-proof fencing; and fails to account for animals not using passage structures or that are resistant to crossing. To address such biases, Clevenger et al. (2001*b*) estimated expected passage frequencies derived from track assessments of relative abundance, and Clevenger and Waltho (2003) calculated species performance ratios from radio telemetry, pellet transects, and habitat suitability indices. Reed et al. (1975) compared animal evidences at the entrance and exits of an underpass to calculate activity indices, while Gordon and Anderson (2003) used behavioral quantification as a measure of wildlife response.

2.2 EXPERIMENTAL APPROACH

The reconstruction of State Route (SR) 260 is one of the most comprehensive projects of its type in North America: eleven large wildlife underpasses[1] and six bridges (1 passage

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[1] Each underpass but one actually consists of two structures with an atrium between them. They will be referred to as single structures herein.

structure/mi) are being built to allow wildlife passage and improve highway safety, This project rivals the landmark efforts to improve wildlife passage and reduce losses from collisions with vehicles in Banff National Park, Alberta, Canada, which has 24 passage structures in 28 mi (0.86 structures/mi; Clevenger and Waltho 2003), as well as those planned for the U.S. Highway 93 reconstruction in Montana, which has 42 passage structures in 56 mi (0.75 structures/mi; Western Transportation Institute 2005).

2.2.1 Phased Construction and Adaptive Management

In addition to its scope in addressing conflicts with wildlife, the SR 260 upgrade is noteworthy for two other reasons: it is being done in phases and information gained in early phases is being used to improve work in later ones.   The section of SR 260 to be upgraded was divided into five parts; each part is being reconstructed according to a priority set by ADOT. These parts are identified by a settlement or prominent feature: Preacher Canyon, Christopher Creek, Kohl's Ranch, Little Green Valley, and Doubtful Canyon. The phasing of reconstruction has facilitated effective construction oversight by ADOT and allowed the sections with higher priority to be done first under limited funding. The incidence of wildlife-vehicle collisions was a key factor used in setting priority for upgrade (Route 260-Payson to Heber EIS, ADOT Environmental Planning Section, Phoenix, AZ).

Doing the reconstruction in phases has also facilitated sharing of our preliminary findings with ADOT project managers for their use in addressing wildlife-related issues. Preliminary insights from studies done in the early phases have been used to improve wildlife passage structures, identify appropriate stretches for ungulate-proof fencing to maximize underpass effectiveness and minimize wildlife-vehicle collisions, and select appropriate sites for other measures (e.g., wildlife escape jumps and gates) in sections whose work is still underway or is yet in the planning stage   Though such an adaptive management approach can yield continuous improvement to the quality of highway construction, especially relating to highway safety, it does come at a potential cost when construction delays and increased project budget expenditures occur.

2.2.2 Experimental Approach

The reconstruction of SR 260 in phases afforded us the opportunity to assess the impact on wildlife of highway reconstruction at various stages. Hardy et al. (2003) and Roedenbeck et al. (2007) stressed the value of conducting "before-after, control-impact" (BACI; Underwood 1994) assessments to determine the effects on wildlife of highway construction and the efficacy of measures to reduce wildlife-vehicle collisions and promote passage. The phased reconstruction of SR 260 and the presence of experimental controls gave us the opportunity to conduct such an assessment. During our research, we assessed wildlife relationships and response to one section that was reconstructed prior to the initiation of research, two where construction was initiated during our project, yielding before-, during- and after-reconstruction data, and two sections that served as research controls (Table 2.1).

Our research focused on evaluating the effectiveness of measures designed to minimize wildlife-vehicle collisions, especially those involving elk, and to maintain wildlife passage across the highway. The first phase was initiated under Joint Project Agreement 01-152, which was executed with ADOT in January 2002. . It focused on the Preacher Canyon section, which was the first to be reconstructed. Work on this section was completed in 2001 (Table 2.1). Research under this phase served as a "pilot study" for the development and evaluation of various techniques for gathering data to use in assessing the effectiveness of the various measures to minimize wildlife-vehicle collisions and facilitate wildlife passage across the highway corridor. Phase II of our project continued through July 2006 under Joint Project Agreement 04-024T, which was executed with ADOT in December 2003. This phase focused on the Christopher Creek section, which in late 2004 became the second section completed (Table 2.1).We also continued monitoring the Preacher Canyon section in this phase. In November 2005, Joint Project Agreement 06-004T was finalized with ADOT, which authorized Phase III of our research. This phase focused on the Kohl's Ranch section, which was completed in early 2006 (Table 2.1); research under this phase will continue through June 2008.

Table 2.1. Dates that highway reconstruction was initiated and completed for the five reconstruction sections on State Route 260, Arizona, and years of research accomplished under various construction classes as part of research conducted 2002–2006.

	Construction upgrade		Years of study by construction class		
Highway section	Begun	Completed	Before	During	After
Preacher Canyon	1999	2001	0	0	5
Christopher Creek	2002	2004	1	2	2
Kohl's Ranch	2003	2006	2	2	1
Little Green Valley	Control		5	0	0
Doubtful Canyon	Control		5	0	0

2.3 RESEARCH OBJECTIVES

Our research addressed six objectives:

Objective 1. Assess and compare wildlife use of wildlife underpasses constructed along State Route 260, and evaluate the efficacy of video surveillance as a means of assessing wildlife use of underpasses.

Researchers have used various methods to gather data to assess wildlife response to passage structures (Hardy et al. 2003), including track counts (Rodríguez et al. 1996; Clevenger et al 2001*b*; Clevenger and Waltho 2000, 2003), event recorders (Reed et al.

1975, Foster and Humphrey 1995), and infrared motion or heat sensor single-frame cameras (Servheen et al. 2003, Brudin 2003, Ng et al. 2004). Video cameras have had only limited use in the past for assessing passage structure use (Reed et al. 1975, Gordon and Anderson 2003, Plumb et al. 2003). Video surveillance has an advantage over other techniques because animal behavior can be assessed, especially when the animal resists or fails to cross (Hardy et al. 2003). Video surveillance also allows identification and classification (e.g., sex, age) of individual animals, which track counts do not (Hardy et al. 2003). Although video camera surveillance has been minimally used to assess use of passage structures, such monitoring has nonetheless provided insights that were not obtained from other methods (Reed et al. 1975, Gordon and Anderson 2003).

To meet this objective, we evaluated the use of video surveillance to assess and compare wildlife response to underpasses constructed during the reconstruction of SR 260 in the first phase of our research. Focusing on the first two completed wildlife underpasses (in the Preacher Canyon section), we tested the hypothesis that wildlife frequency of use, passage rates, and behavioral response did not differ at these underpasses and we evaluated the efficacy of using passage rate and behavioral response measures to compare wildlife use of passage structures. We explored seasonal wildlife use and response at the two underpasses, related differences in response to underpass characteristics where possible, and considered relationships with highway traffic volume.

Under Phase II, we expanded monitoring and assessment to the underpasses constructed on the Christopher Creek section with three additional video surveillance systems. Information from these underpasses is still preliminary, especially compared to the relatively long term monitoring conducted at the two underpasses in the Preacher Canyon section as part of Phase I. Our sixth video camera surveillance system was installed at an underpass on the Kohl's Ranch section as part of Phase III of our project; this data is also preliminary.

Our findings for this objective are reported in Sections 4 and 11.

Objective 2. Evaluate wildlife movements across SR 260 before, during, after reconstruction using Global Positioning System (GPS) telemetry.

The use of GPS telemetry in 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 studies. GPS telemetry is increasingly used to address previously-difficult questions (e.g., Anderson and Lindzey 2003), and holds tremendous potential to facilitate highway passage assessment and determine spatial and temporal highway crossing patterns of wildlife.

Under this objective, we used GPS telemetry to investigate elk passage across SR 260, comparing their approach, crossing, and passage rates by sections before, after and at intermediate stages of construction. We evaluated quantitative measures of elk highway passage using GPS telemetry; and assessed spatial and temporal influences on elk movements. We conducted separate GPS telemetry assessments under Phases I and II of our research, with a third assessment ongoing in conjunction with research Phase III.

Our findings for this objective are reported in Sections 6 and 7.

Objective 3. Characterize the temporal and spatial patterns of wildlife-vehicle collisions and changes associated with highway reconstruction (before, during, after reconstruction), and compare wildlife-vehicle collisions to GPS-determined crossing patterns.

Under this objective, we characterized the nature of elk-vehicle collision patterns along SR 260, and compared collision incidence associated with the highway before, during, and after reconstruction. We sought to validate the priority for reconstruction set for the highway sections based on wildlife-vehicle collisions. We compared spatial and temporal patterns of elk-vehicle collisions to elk-highway crossings determined by GPS telemetry as a means to validate the management utility of elk-vehicle collision data in developing strategies to reduce collisions and promote passage. Overall, this objective focused on evaluating the ultimate effectiveness in reducing elk-vehicle collisions of the full complement of measures (e.g., wildlife underpasses and ungulate-proof fencing) implemented along SR 260, as well as the benefit/cost relationships of such measures.

We reported the results of our research for this objective in Section 9.

Objective 4. Evaluate the relationships among highway traffic volume and wildlife-vehicle collisions, elk crossing patterns, and wildlife use of underpasses.

Although researchers disagree about whether increasing traffic volume is the primary reason for increasing ungulate-vehicle collisions (McCaffery 1973; Reilly and Green 1974; Allen and McCullough 1976; Case 1978; Romin and Bissonette 1996), many recognize that traffic volume is an important factor, among others such as wildlife population fluctuations, wildlife behavior, driver behavior, and temporal and spatial environmental factors (Carbaugh et al. 1975, Bashore et al. 1985, Groot Bruinderink and Hazebroek 1996, Haikonen and Summala 2001, Seiler 2004, Gunson and Clevenger 2003, Manzo 2006).

Traffic may serve as a “moving fence” that can render highways impassable to wildlife (Bellis and Graves 1978). One theoretical model (Iuell et al. 2003) predicted that highways become impassable barriers to most wildlife at 10,000 vehicles/day, potentially leading to fragmentation and rapid genetic isolation like that documented for bighorn sheep (Epps et al. 2005). Alternatively, because traffic varies seasonally, weekly and by time of day, some animals may be able to cross highways with high traffic volume during periods when traffic volume is relatively low.

Average annual daily traffic (AADT) along SR 260 is high and is increasing due to the tourist, recreational, and commercial traffic that travels this highway. SR 260 links Phoenix to White Mountain communities (e.g., Show Low, Pinetop-Lakeside, Springerville-Eagar) and high-mountain recreation areas (e.g., White Mountain Apache

Reservation, Apache-Sitgreaves National Forest), as well as Interstate 40. We used GPS telemetry data to assess relationships of AADT to elk distribution and highway approach and crossing patterns so as to assess the impact of traffic volume at highway grade. At wildlife underpasses, we assessed the relationships of traffic volume on wildlife crossing below grade.

Our findings from traffic volume-related research are reported in Sections 5 and 8.

Objective 5. Assess the role that ungulate-proof fencing plays in the incidence of wildlife-vehicle collisions, wildlife use of underpasses, and wildlife permeability across the highway.

Research has shown that ungulate-proof fencing effectively reduces wildlife-vehicle collisions, especially when used in conjunction with passage structures (Ward 1982, Lavsund and Sandegren 1991, Romin and Bissonette 1996, Clevenger et al. 2001, Forman et al. 2003). Though fencing is generally regarded as effective in reducing collisions with wildlife, mixed results have been reported (Falk et al. 1978), especially where animals cross at the ends of fencing resulting in zones of increased collisions (Feldhamer et al. 1986, Woods 1990, Clevenger et al. 2001). Furthermore, fencing is costly and requires substantial maintenance (Forman et al. 2003), potentially contributing to transportation managers' reluctance to fence extensive stretches of highways. 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 use of fencing with wildlife passage structures. As fences themselves constitute effective barriers to ungulate passage across highways (Falk et al. 1978), fencing may exacerbate the barrier effect associated with highways alone (see Section 6), particularly where effective measures to accommodate animal passage are lacking.

During the reconstruction of SR 260, ADOT's practice of integrating 8-ft ungulate-proof fencing with underpasses and bridges has been to erect limited wing fences (fewer than 300 ft) outward from bridge abutments to funnel animals toward the structures. As part of our research, we addressed the efficacy of this approach to fencing and used the adaptive management approach during reconstruction to recommend and evaluate the strategic placement of fencing to intercept crossing wildlife, reduce wildlife-vehicle collisions, promote effective use of underpasses by wildlife, and maintain highway permeability.

The results of our research related to the role of ungulate-proof fencing are found in Section 7.

Objective 6. Provide ongoing, highway construction and maintenance guidance throughout all construction phases.

As our research was part of an ongoing adaptive management approach to the highway reconstruction project; we provided guidelines for maintaining wildlife permeability, minimizing wildlife-vehicle collisions, improving wildlife underpass design to maximize the likelihood of high acceptance and use by wildlife, and the strategic placement of ungulate-proof fencing.

We report the results and applications of the adaptive management part of our project in Sections 4, 6, 7, and 11.

2.4 REPORT ORGANIZATION

This report has our findings from Phases I and II, and to a limited degree Phase III. First, we describe the study area to set the context for our research. The research conducted to meet our objectives is reported in the following sections. In the Conclusion and Recommendations section, we tie together the information from the previous sections.

3.0 STUDY AREA

We conducted this study along a 17-mi stretch of SR 260, beginning 9 mi east of Payson, and extending to the base of the Mogollon Rim in central Arizona (lat 34°15'–34°18'N, long 110°15'–111°13'W; Figure 3.1). The existing two-lane highway is being upgraded to a four-lane divided highway (Figure 3.1). In places, the footprint of the upgraded highway exceeds 0.3 mi in width (Figure 3.2). When completed, the highway will have 11 wildlife underpasses specifically intended to reduce at-grade elk crossings and elk-vehicle collisions, as well as six bridges over large canyons and streams that will accommodate wildlife use (Figure 3.1, Table 3.2). All but one of the underpasses consists of two structures, one for each roadway, with an atrium between them. The highway reconstruction is being done in five phases, each phase focusing on a single section (Figure 3.1, Table 3.2). Reconstruction of three sections is now complete.

The Preacher Canyon section was the first completed; all lanes were opened to traffic in November 2001. This section has two bridged underpasses and a large bridge over Preacher Canyon (Figure 3.1); 0.4 mi (13%) of the section was fenced with 8-ft ungulate-proof fencing associated with the two underpasses near Little Green Valley. The Christopher Creek section was completed in December 2004; it has had four wildlife underpasses and three bridges in place since 2003. All lanes in the Christopher Creek section were opened to traffic in July 2004 before all fencing associated with the underpasses was completed. Here, fencing and alternatives to fencing (e.g., swaths of large rock rip-rap) were implemented along half the section in association with passage structures. The Kohl's Ranch section, the most recently reconstructed, was completed in March 2006; this section has one wildlife underpass and 1.5 bridges (only one bridge span was built over Thompson Draw, with the other to be done under the Little Green Valley section). Reconstruction of the Little Green Valley and Doubtful Canyon sections will be in or after 2008.

Table 3.1. State Route 260 reconstruction sections, reconstruction status, mileposts and length, and the number of wildlife passage structures planned or built as part of the reconstruction.

Highway section	Reconstruction status	Highway mileposts	Length (mi)	Wildlife passages	
				Underpasses	Bridges
Preacher Canyon	Completed 2001	260.0–263.0	3.0	2	1
Little Green Valley	Control	263.1–265.5	2.5	1	0.5
Kohl's Ranch	Completed 2006	265.6–269.5	4.0	1	1.5
Doubtful Canyon	Control	269.6–272.5	3.0	3	0
Christopher Creek	Completed 2004	272.6-277.0	4.5	4	3
All		260.0-277.0	17.0	11	6

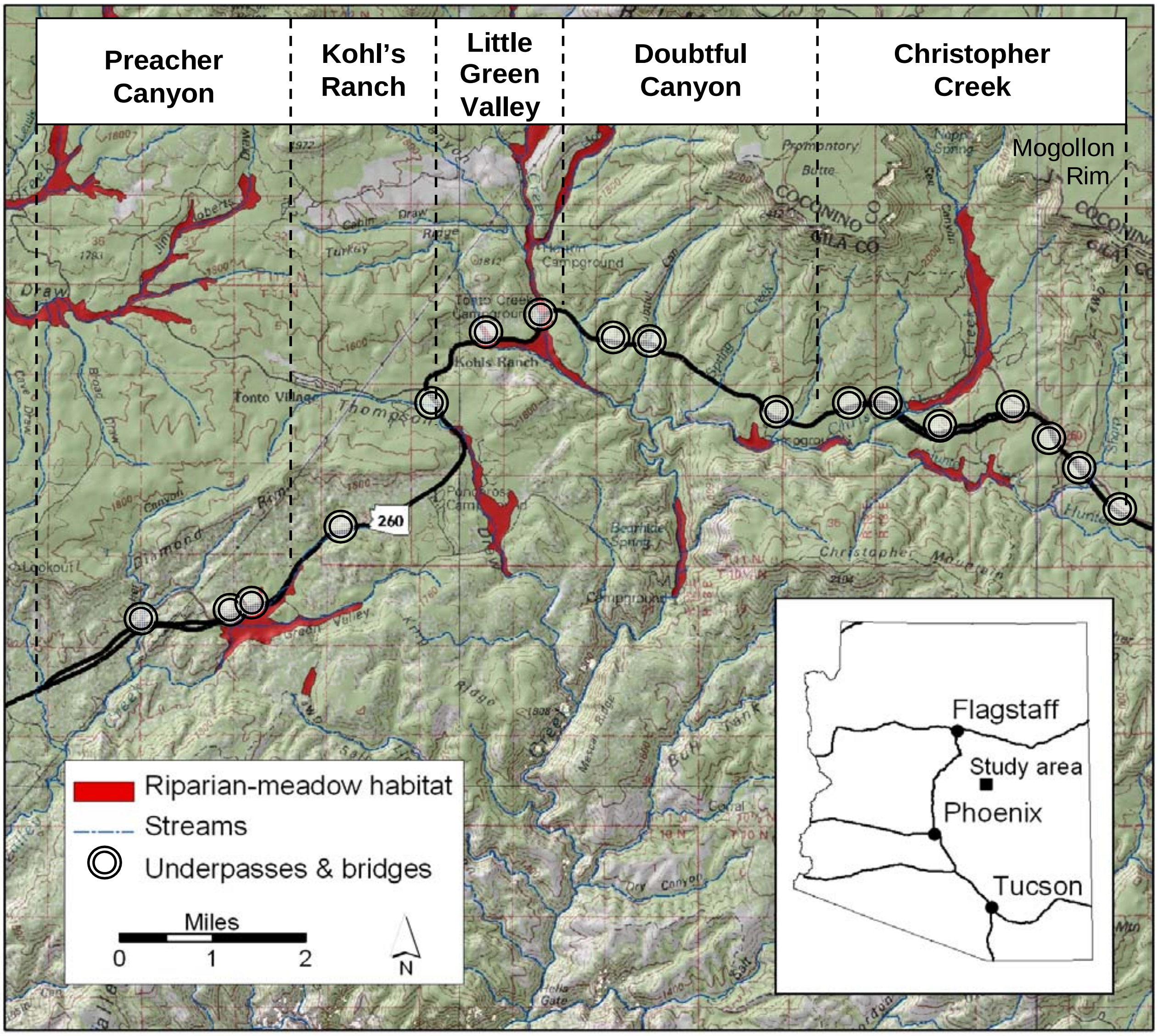

Figure 3.1. Location of our study area and the five highway sections where phased highway reconstruction has been ongoing since 2000, and the location of wildlife underpasses and bridges. The shaded areas correspond to riparian-meadow habitats located adjacent to the highway. Topographic relief reveals the study area's proximity to the Mogollon Rim escarpment, the dominant physiographic feature within the study area.

Figure 3.2. The existing narrow two-lane roadway (left; Doubtful Canyon section) is being reconstructed to a four-lane divided highway (right; Preacher Canyon section), State Route 260, Arizona.

Our study area lies within the ponderosa pine (*Pinus ponderosa*) association of the montane coniferous forest community (Brown 1994*a*). Elevations along SR 260 range from 5,220–6,560 feet (ft.) The Mogollon Rim escarpment to the north is the dominant landform, rising precipitously to 7,860 ft (Figures 3.1 and 3.3). Vegetation adjacent to the highway grades from mixed forest of ponderosa, pinyon (*P. edulis*), juniper (*Juniperus spp.*), and live oak (*Quercus spp.*) on the lower elevation Preacher Canyon and Little Green Valley sections, to forests predominated by ponderosa with interspersed Gambel oak (*Q. gambelii*) at higher elevations to the east (Christopher Creek section). Chaparral (e.g., manzanita; *Arctostaphalos pungens*) with sparse pinyon, live oak, and ponderosa pine is prevalent on the drier south-facing slopes. In canyons emanating from the Mogollon Rim within our study area, mixed-conifer forest of ponderosa pine, Douglas fir (*Pseudotsuga menzeisii*), white fir (*Abies concolor*) and Gambel oak are found. Numerous riparian and wet meadow habitats occur at several locations along the highway corridor (Figure 3.1); some meadows are more than 60 acres (Figure 3.4). Several perennial streams flow adjacent to portions of the highway, including Little Green Valley Creek (Preacher Canyon, Little Green Valley sections), Tonto Creek (Kohl's Ranch section), Christopher Creek (Doubtful Canyon, Christopher Creek sections), Hunter Creek (Christopher Creek section), and Sharp Creek (Christopher Creek section) (Figure 3.1).

Climatic conditions within the study area are mild, with a mean maximum monthly temperature (July) for Payson of 90.3º F, and mean minimum monthly temperature (January) of 19.6º F. Annual precipitation averages 20.7 inches (in.), with a mean of 21.3 in. of snowfall in winter; precipitation has averaged ⅔ of normal since 2002.

Average annual daily traffic (AADT) 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 (Figure 3.5; 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).

Figure 3.3. State Route 260 study area (at the pedestrian/wildlife underpass on the Christopher Creek Section), Arizona. The Mogollon Rim escarpment rises in the distance above ponderosa pine forest adjacent to the highway corridor. The solar panels power our video camera surveillance system to monitor wildlife use of the underpass.

Figure 3.4. Aerial view of Little Green Valley riparian-meadow complex adjacent to the Preacher Canyon section. Such habitats are very important to wildlife for food and water, especially in proximity to forest cover.

Rocky Mountain elk (*Cervus elaphus nelsoni*) were a focus of our research for several reasons. First, elk accounted for more than 80% of all collisions between vehicles and wildlife (Dodd et al. 2006) and the vast majority of property loss and human injuries associated with these collisions. Elk are large animals that can readily support our GPS telemetry collars, yielding substantial long-term data on movements in relation to the highway corridor, and were relatively easy to trap.

Our study area has both resident and migratory elk herds. Resident elk were common, especially near meadow and riparian habitats. Migratory elk come off the Mogollon Rim with the first snowfall of more than 12 in., typically in late October (Brown 1990, 1994*b*). Brown (1990) reported that 85% of the elk residing within his Mogollon Rim herd unit migrated to an area below but within six mi 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). The Arizona Game and Fish Department estimated the resident elk population in the 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. White-tailed deer (*Odocoileus virginianus cousei*) were frequently seen in our study area, while mule deer (*O. hemionus*) were less common and more localized on the Christopher Creek section.

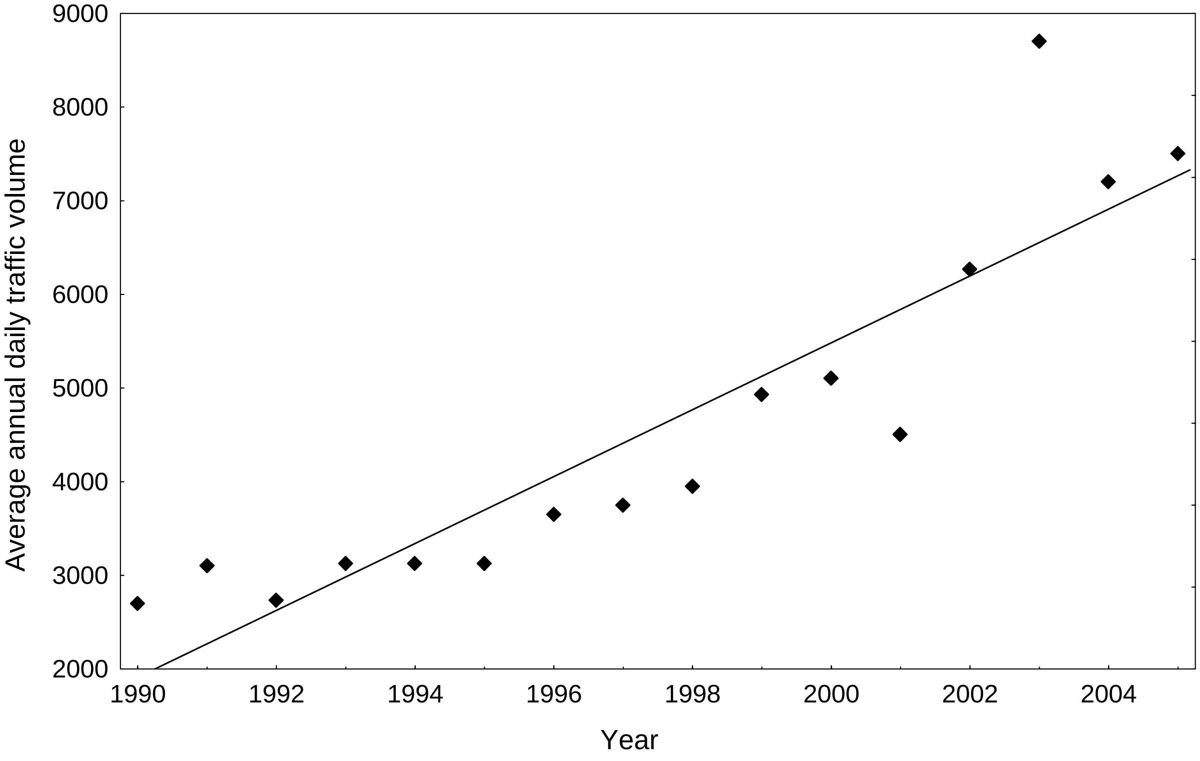

Figure 3.5. Average annual daily traffic for State Route 260, Arizona. (ADOT Control Road monitoring station) for the period 1990–2005.

4.0 VIDEO SURVEILLANCE TO ASSESS HIGHWAY UNDERPASS USE BY ELK [2]

4.1 INTRODUCTION

Recognition of highways' impact on wildlife has increased dramatically in the past decade (Forman et al. 2003). In addition to direct habitat loss (Forman 2000), mortality from vehicle collisions has been recognized as a serious and growing problem for wildlife and motorists (Reed et al. 1982, Farrell et al. 2002). Annual vehicle collisions with deer alone in the U.S. exceed 1.5 million (Conover 1997). Highways play a pervasive role as barriers to free movement of wildlife, fragmenting and isolating habitats, reducing genetic interchange (Epps et al. 2005), and increasing population susceptibility to catastrophic events (Forman and Alexander 1998, Trombulak and Frissell 2003).

Structures designed to promote wildlife passage across highways are increasingly being built, particularly large bridges designed specifically for large animal passage (Clevenger and Waltho 2000). Whereas in the past managers typically built early passage structures as single-species mitigations (Reed et al. 1975), managers today have directed their focus toward preserving habitat continuity to benefit multiple species (Clevenger and Waltho 2000). Transportation agencies are increasingly receptive to building passage structures to meet safety and ecological needs (Farrell et al. 2002), and there is increasing expectation that they will indeed yield desired benefits (Clevenger and Waltho 2000). Scientifically sound monitoring of wildlife response to passage structures is crucial to improving future effectiveness (Clevenger and Waltho 2003, Hardy et al. 2003).

Researchers have used various techniques to measure wildlife use of passage structures (Hardy et al. 2003), including track counts (Rodríguez et al. 1997; Clevenger et al 2001*a*; Clevenger and Waltho 2000, 2003), triggered event recorders or counters (Reed et al. 1975, Foster and Humphrey 1995), and infrared motion or heat sensor single-frame cameras (Brudin 2003, Servheen et al. 2003, Ng et al. 2004). Video cameras have had only limited use (Reed et al. 1975, Sips et al. 2002, Gordon and Anderson 2003, Plumb et al. 2003).

Several measures have been used to describe wildlife use of passage structures. Most studies have enumerated frequency of use (Clevenger and Waltho 2000, Gloyne and Clevenger 2001, Sips et al. 2002, Ng et al. 2004). However, frequency of use may be a biased index of passage structure efficacy. It is subject to differential funneling of animals by varying amounts of fencing and heterogeneous animal distribution, and does not account for non-use attributable to structure characteristics or alternative crossing locations, as addressed by Reed et al. (1975), Clevenger et al. (2001*a*), and Clevenger and Waltho (2003, 2005).

Video surveillance has advantages over other techniques for assessing passage because managers can evaluate animal behavior, especially when the animals resist - or don't

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[2] An early version of this chapter was published in the *Journal of Wildlife Management* (see Dodd et al. 2007*a*)

complete - crossing (Hardy et al. 2003, Gordon and Anderson 2003). Though few studies have used video surveillance to assess use of passage structures, such monitoring has provided insights that could not be obtained from other methods (Reed et al. 1975, Gordon and Anderson 2003, Plumb et al. 2003).

Our objective was to evaluate video surveillance for assessing and comparing wildlife response to underpasses. We examined Rocky Mountain elk use of the first two underpasses completed as part of the SR 260 reconstruction. We tested hypotheses that elk passage rate (crossing frequency/approach frequency), probability of use, and behavioral response did not differ at the two underpasses. We monitored seasonal elk use of the underpasses to test the hypothesis that passage rates and probability of use did not differ by season. We related differences in elk use to underpass design and provided guidelines for future design to maximize the likelihood of use by elk and other wildlife.

4.2 STUDY AREA

We conducted our study at two bridged underpasses constructed specifically for wildlife passage along the Preacher Canyon section of SR260 (Figure 4.1). Both opened to the south into Little Green Valley, a relatively lush riparian-meadow foraging area contrasted by dense forest cover on the north side of the highway (Figure 4.1). The two underpasses were less than 850 ft. apart (Figure 4.1). Though both were of similar open-span bridge construction and length (135 ft), the below-span characteristics and dimensions were markedly different (Figure 4.1, Table 4.1). The east underpass had vegetated earthen sides that made it more open and natural compared to the west underpass, which had concrete, mechanically stabilized earth (MSE) walls (Figure 4.1). ADOT installed 8 ft high ungulate-proof fencing along 0.4 mi of the highway to funnel animals to the two underpasses (Figure 4.2).

Table 4.1. Physical characteristics associated with the two wildlife underpasses (UP) at which we conducted video monitoring focusing on elk from September 2002–September 2005, State Route 260, Arizona. (see Figure 4.1).

Characteristic	East UP	West UP
Construction type	Open I-beam span	Open I-beam span
Bridge span distance	135 ft	135 ft
Maximum height above floor (H)	22 ft	38 ft
Atrium (between bridges)[a]	36 ft	36 ft
Width at floor (W)	32 ft	52 ft
Length[b] (L)	175 ft	365 ft
Side construction	2:1 sloped earth/vegetation	MSE[c] concrete walls to 20 ft
Openness ratio[d]	12.3	5.5

[a] - Atrium = width of opening between eastbound and westbound bridge spans at each underpass
[b] - Length = distance for animals to fully negotiate underpass, including fill at mouth of underpass
[c] - MSE = mechanically stabilized earth
[d] - Openness = (W × H) / L (Reed et al. 1979)

Figure 4.1. Little Green Valley riparian-meadow complex (center photo) adjacent to State Route 260 in Arizona, into which the west (top photo) and east (bottom photo) wildlife underpasses open. Note their proximity and the different soil stabilization features, the west with concrete walls, and the east with 2:1 sloped earthen sides.

4.3 METHODS

4.3.1 Video Surveillance System Components and Layout

At each underpass we installed video surveillance systems comprised of four low-lux, high-resolution black and white (B&W) video cameras linked to a 12-volt videocassette recorder (VCR) with alarm input and a B&W quad-screen splitter. To illuminate the area covered by our cameras, we installed infrared (IR) 60 LED illuminators (9 at the east underpass, 7 at the west). We used five IR photo-beam triggers at each underpass to detect approaching and crossing animals. We operated both systems on 120-volt AC power converted to 12-volt DC power for distribution to all equipment via buried wiring. We operated the camera systems at the east underpass from September 2002–September 2005; the camera system at the west underpass we operated from November 2002–September 2005.

At each we oriented our video systems to record animals approaching from the north side only (Figure 4.2), recording the elk as they traveled from forest cover into Little Green Valley. We believe that elk that approached from the north had a greater degree of discretion in use of the underpasses or alternate crossing locations compared to elk already in Little Green Valley that had to return to cover via an underpass. Nonetheless, we recorded animals crossing from both the north and south. We installed two cameras approximately 100–115 ft from each underpass (Figure 4.2) to record animals approaching to within approximately 200 ft. of the underpass along drainages leading to it. We mounted a camera atop a 15-ft pole in each underpass to record animals entering and crossing. We oriented a camera toward the highway to record traffic, while other cameras simultaneously recorded approaching or crossing wildlife (Figure 4.2); we reported results of this monitoring in Gagnon (2006).

We placed IR photo-beam triggers approximately 1.5 ft above ground oriented such that animals could not approach the underpass without tripping a trigger. To avoid recording delays, we operated all components continuously so that VCRs immediately began recording when triggered, with all cameras recording simultaneously. We programmed our VCR alarm to record for two minutes each time an animal successively tripped a trigger. Twelve-volt DC blowers and heaters ensured continuous operation during heat and cold.

4.3.2 Video Data Analysis

We extracted the following data from the video tape: date, time of day, total time animals spent in the area, species, sex, age, number of animals, number of animals approaching and crossing through the underpass, direction of travel, and various behaviors.

We calculated monthly elk passage rates as the proportion of elk groups that passed through the underpass from the north relative to the frequency of groups that approached from the same direction. We counted as an approach when animals crossed over the 3.5 ft right-of-way (ROW) fence approximately 130–160 ft from the mouth of the underpass (Figure 4.2). ADOT did not remove this fence during underpass construction due to presence of livestock; instead, at each underpass it threaded the top two stands of wire through 20-ft lengths of PVC pipe to create elk jumps. We counted it as a group crossing when half or more the elk in a group passed through an underpass.

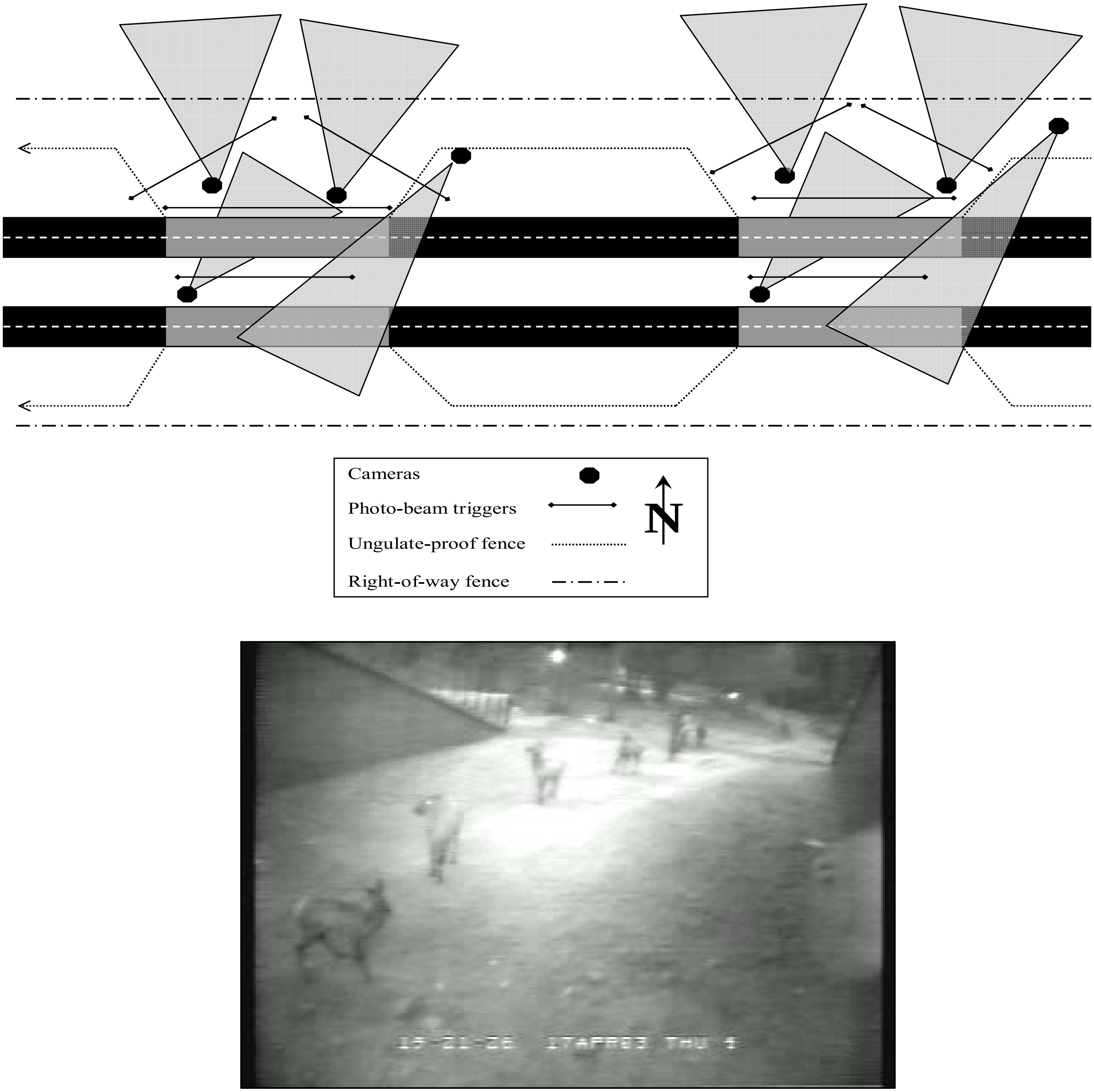

Figure 4.2. Layout (top) of video surveillance system components at the west and east Little Green Valley wildlife underpasses and the location of elk-proof and highway right-of-way fencing, State Route 260, Arizona. We oriented video cameras to record wildlife approaching each underpass from the north (2 cameras), animals crossing through the underpass from both the north and south (1 camera), and simultaneous traffic on the highway while animals approach and pass through the underpass (1 camera). The bottom photo shows a group of elk passing through the west underpass, though the lead cow is showing resistance. Note the illumination provided by infrared lights to observe animals at nighttime.

We classified behavioral responses of individual elk into five approach and three crossing categories to quantify acceptance or resistance to using the underpasses, similar to Gordon and Anderson (2003). For approaching elk, we assigned frequencies to 1 or more of these categories:

- *Would not cross* – elk left without crossing an underpass.
- *Enter underpass and retreat* – elk entered an underpass but retreated outside it.
- *Alarmed flight* – elk that approached or entered an underpass, but rapidly departed in an alarmed manner.
- *Feeding in area* – elk that fed in the area between the ROW fence and the center of an underpass.
- *Standing or milling about* – elk that stood or milled about in the area between the ROW fence and center of an underpass.

For elk that crossed through either underpass from the north, we classified the degree to which they exhibited hesitation or paused in an alert posture (excluding feeding behavior). We quantified delay by the time it took the elk to move from the mouth to beyond the center of the underpass:

- *No delay* – elk crossed with less than 10 seconds combined hesitation.
- *Minor delay* – elk crossed with 11-30 seconds combined hesitation.
- *Obvious delay* – elk crossed after a combined delay more than 30 seconds. We classified elk that retreated or fled in alarm from the underpass before finally crossing as exhibiting obvious delay.

4.3.3 Time-Lapse Validation

We conducted 24-hour time-lapse taping on five occasions at both underpasses to compare the number of elk groups and individual animals recorded by VCRs in time-lapse mode to the number recorded when the VCR alarm log reflected that animals had activated a photo-beam trigger. We relied on our VCR internal alarm counters while viewing the time-lapse video recordings to determine what proportion of approaching and crossing animals our photo-beam triggers detected.

4.3.4 Statistical Analysis

Clevenger and Waltho (2000) stressed the benefit of multi-species assessments of passage structure use, and Little et al. (2002) raised issues regarding predator-prey interactions at passage structures. Though we pursued a multi-species assessment (see Gagnon et al. 2006), our observations for most species were relatively small compared to those for elk, which accounted for more than 90% of the animals recorded on our videotapes. This limited our ability to make statistical inferences regarding underpass use for species other than elk.

We used elk group observations to assess underpass use to address potential bias from lack of independence associated with individual animal observations attributable to the herd nature of the species. Like Clevenger and Waltho (2000), we assumed that since our underpasses were in homogeneous habitat: 1) both served the same elk population, and 2) elk were aware of both and could choose between them based on their attributes alone. This was particularly true in our case as the two underpasses were less than 850 ft. from each other and elk could readily see them from throughout Little Green Valley when looking north.

We used a general linear model with a logit link (Agresti 1996) to asses the probability of elk use at the two underpasses, based upon the binary response when they approached an underpass:

1 = approached and crossed, and
2 = approached and did not cross.

We incorporated underpass (east and west), season (summer and winter), and year (2003-2005) in our modeling to assess their influence on the probability of elk use, and we addressed pairwise interactions among variables. The winter season (October–March) corresponded to the period when migratory elk from atop the Mogollon Rim were present along SR 260 (Brown 1990), while presumably only resident elk were present during the summer season (April–September). We computed 95% confidence intervals (CI) for the probability of elk making a successful underpass crossing using outputs from our logistic regression modeling (Agresti 1996); differences between probabilities of underpass use were significant when CI did not overlap.

We employed the Bradley-Terry model, a logistic regression model for paired preferences (Agresti 1996), to determine underpass preference (east versus west) with regard to groups of elk approaching (from the north only) and crossing (from the north and south separately and combined) at our two underpasses. This model does not require independence of observations (Agresti 1996), and thus it was suited to addressing our concern that some of our observations were likely comprised of the same elk. The model yielded 95% CI for the probability that elk will select one underpass over the other (Agresti 1996).

We compared behavioral response of approaching and crossing individuals (versus groups, as multiple behaviors could be exhibited within the same group) at each underpass. We calculated two-proportion 95% CI to display the magnitude of differences between underpasses for each behavior (Agresti 1996).

We used a chi-square goodness-of-fit test to compare observed to expected elk group underpass crossings by day. We assessed the effect of daily traffic volume on elk group underpass crossings by calculating daily AADT factors (daily AADT/mean daily AADT) that account for differential daily traffic volume (e.g., 9,378 on Friday [factor = 1.30] versus 5,433 on Tuesday [factor = 0.75]). We calculated weighted daily elk underpass crossings by dividing underpass crossings by daily AADT factors; we compared weighted underpass crossings to expected crossings with a chi-square test. We obtained daily AADT from a permanent ADOT traffic counter installed near the two underpasses in December 2003, with daily AADT averaged through December 2004.

4.4 RESULTS

We recorded on 793.2 hr of videotape eight species of wildlife accounting for 4,083 animals in 1,495 groups at the two wildlife underpasses. Elk accounted for 90.8% of the individuals and 84.7% of the groups. We classified 3,708 elk (2,581 cows, 299 bulls, 633 calves, 165 unclassified) in 1,266 groups (mean = 2.93 elk/group ±0.13 SE) with a range of 1–31 members. Of the elk, 2,612 individuals and 905 groups crossed through an underpass, for overall passage rates of 0.63 and 0.62, respectively (Table 4.2).

Elk exhibited a bimodal pattern in the timing of crossings associated with sunset and sunrise (Figure 4.3). A peak in crossings toward the Little Green Valley meadow complex occurred between 5:00 and 10:00p.m.; crossings peaked again as elk returned through the underpass between 4:00 and 7:00a.m. (Figure 4.3). Twelve individual elk crossed between 9:00 a.m. and 4:00p.m.. The frequency of crossing varied by day of the week, with highest on days with lowest traffic volume (Figure 4.4), though observed crossings did not differ from expected (χ^2_6= 10.32, $P = 0.111$). However, when we applied daily AADT factors to account for traffic volume, weighted underpass crossings differed from expected (χ^2_6= 78.50, $P < 0.001$).

We recorded nearly three times the number of elk groups at the east (663) versus west (242) underpass (Table 4.2). In all cases, elk showed a preference for approaching and crossing at the east underpass (Table 4.2). When crossing the underpass from the north, leaving cover toward Little Green Valley, elk preference was particularly strong, with a 0.79 probability of selecting the east over the west underpass (Table 4.2). Overall, the passage rate for the east underpass (0.75) was higher than that for the west (0.66), though 95% CI overlapped, as did passage rates for summer and winter (Table 4.3).

Among variables used in our multiple logistic regression model, the effect of year was not significant (Wald $\chi^2 = 3.0$; $P = 0.222$), regardless of interaction with other variables or whether we used it as a continuous or ordinal variable (to account for elk habituation) or as a nominal variable (to account for environmental parameters such as precipitation or availability of food). As such, we removed year from further logistic regression analysis. The probability of elk using the two underpasses, however, did vary by season and underpass (Table 4.3); season had a considerably greater effect on elk use (Wald χ^2 = 40.3; $P < 0.001$) than underpass ($\chi^2 = 7.2$; $P = 0.007$).

The probability of elk approaching and crossing the underpass in summer (0.81), regardless of underpass, was considerably higher than the probability of winter use (0.58) (Table 4.3). This corresponds closely with the significantly different seasonal underpass passage rates (Table 4.3). Once we initiated video monitoring 15 months after the two underpasses were completed, the combined elk passage rate for individuals during the first month of video surveillance at both underpasses (January 2003) was less than 0.25 (Figure 4.5). The passage rate steadily climbed until it averaged 0.84 during summer 2003 (June–August 2003; Figure 4.5), before again dropping to less than 0.40 in October 2003. The same seasonal pattern occurred through 2004–2005 (Figure 4.5).

The probability of elk using the east underpass (0.75) was higher than the probability of their using the west underpass (0.66), regardless of season (Table 4.3). With the effect of both season and underpass, the probabilities of elk use of the east underpass were higher than the probabilities of elk use of the west underpass in both summer and winter (Table 4.3).

Most behaviors displayed by elk approaching and crossing the underpasses were dependent on underpass (Table 4.4). Elk displayed a higher proportion of behaviors indicative of resistance to crossing when approaching the west versus east underpass (Table 4.4), particularly those that approached, but would not cross the underpass.

Table 4.2. Results obtained from the Bradley-Terry logit model for paired preferences to assess elk preference in selection of two wildlife underpasses (UP) on State Route 260, Arizona, for approaching and crossing. We based modeling on frequency of group observations recorded on videotape from September 2002–September 2005. Preference, probability estimates (p_e), and 95% CI reflect the probability that elk will select one underpass over the other based on the logit model.

	No. elk observations		Probability of selection		
Elk behavior	East UP	West UP	p_e	95% CI	Preference
Total crossings	663	242	0.72	0.68–0.75	East
Approaches	419	257	0.63	0.60 – 0.66	East
Crossings from N	347	79	0.79	0.74–0.83	East
Crossings from S	316	163	0.70	0.68–0.71	East

Table 4.3. Probabilities (p_e) of use of two wildlife underpasses (UP) by elk groups and 95% confidence intervals (CI) obtained from multiple logistic regression given the combined effects of underpass (east versus west) and season (summer [April–September] versus winter [October–March]), and elk passage rates and two-proportion 95% CI for the same underpass use categories. Modeling based on video surveillance conducted September 2002–September 2005, State Route 260, Arizona.

Elk UP use category	p_e	95% CI	Passage rate	2-proportion 95% CI
East UP regardless of season	0.75	0.73–0.79	0.75	0.70–0.79
West UP regardless of season	0.66	0.62–0.70	0.66	0.61–0.72
Summer regardless of UP	0.81	0.79–0.84	0.82	0.78–0.85
Winter regardless of UP	0.58	0.54–0.63	0.59	0.54–0.59
East UP in summer	0.85	0.81–0.88	0.84	0.79–0.89
West UP in summer	0.77	0.77–0.77	0.78	0.71–0.84
East UP in winter	0.64	0.64–0.64	0.65	0.58–0.71
West UP in winter	0.52	0.44–0.61	0.52	0.43–0.61

Table 4.4. Proportion of individual elk that displayed various behaviors near the two wildlife underpasses (UP) while approaching and crossing, and the associated 95% CI for differences in the proportions (Agresti 1996). We classified behaviors from videotapes recorded September 2002–September 2005, State Route 260, Arizona.

	Proportion displaying behavior			
Elk behavior displayed	East UP	West UP	95% CI	Result
No delay in crossing	0.65	0.60	-0.01–0.12	East UP = West UP
Minor delay in crossing	0.18	0.19	-0.05–0.04	East UP = West UP
Obvious delay in crossing	0.16	0.22	0.01–0.10	West UP > East UP
Would not cross	0.25	0.44	0.15–0.24	West UP > East UP
Enter UP and retreat	0.12	0.21	0.05–0.14	West UP > East UP
Alarmed flight	0.11	0.21	0.06–0.14	West UP > East UP
Feeding in area	0.22	0.47	0.20–0.29	West UP > East UP
Standing or milling about	0.43	0.50	0.03–0.12	West UP > East UP

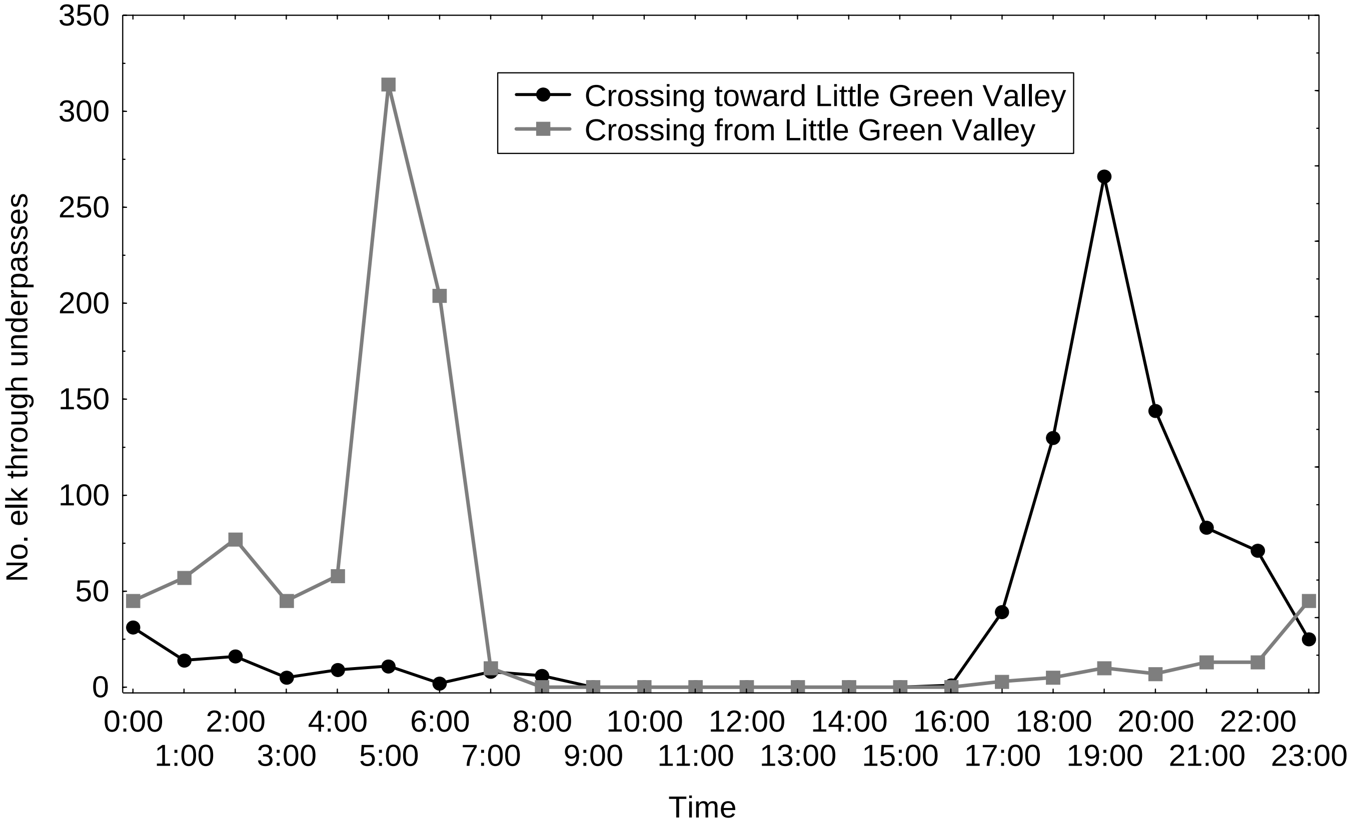

Figure 4.3. Frequency of elk crossing through both wildlife underpasses by time, crossing toward and returning from the Little Green Valley meadow–riparian complex, State Route 260, Arizona, determined from video surveillance from September 2002–September 2005.

4.4.1 Time-Lapse Validation

During our video system validation, we detected a high proportion of animals with our triggers that we recorded in time-lapse mode. At the east underpass, we detected 100% of approaching groups (*n* = 12) and individual elk (*n* = 48) recorded in time-lapse mode by the triggered alarm input.

Of the 11 groups that subsequently crossed, we detected all by both VCR recording modes, and we observed 95.6% of individual elk (44/46) recorded in time-lapse mode when alarm input was triggered; the two missed elk crossed simultaneously with another elk, not allowing the trigger to reset. At the west underpass, we detected 100% of four groups and 18 individual elk that we recorded in time-lapse mode as they approached and crossed by the alarm input.

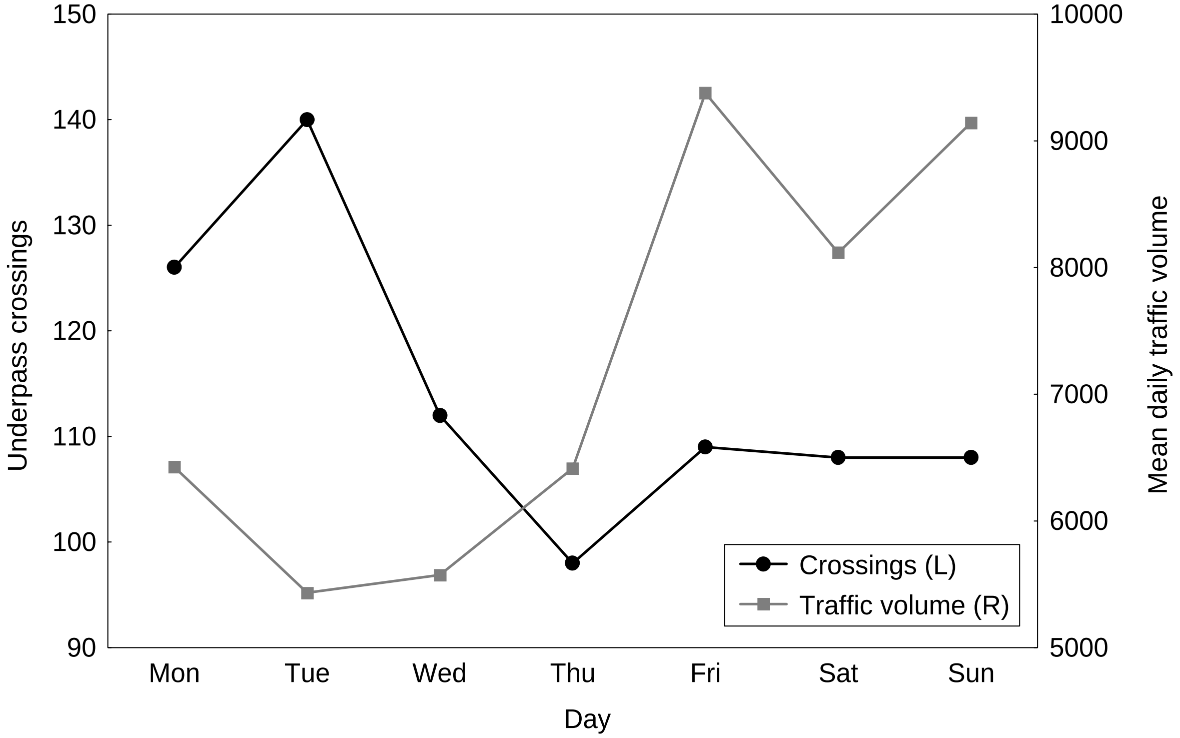

Figure 4.4. Frequency of elk observed crossing at the two Little Green Valley wildlife underpasses by day determined by video surveillance from September 2002–September 2005, and average daily traffic volume determined from a traffic counter along State Route 260, Arizona, for the period December 2003-December 2004

4.5 DISCUSSION

Our results for passage rates, probabilities of underpass use, and behavioral response led us to reject our hypotheses that no differences existed in elk use between underpass and season. The concurrence among these measures underscored the degree of differences in elk use of the two underpasses. Elk use was dependent on underpass, and elk exhibited consistent preference for the east underpass.

Our assessment of only two underpasses precluded analysis and modeling of structural factors accounting for differences in wildlife use, as did Clevenger and Waltho (2000, 2005) and Ng et al. (2004). Reed et al. (1979) recommended that underpass openness ratios (width × height/length) should be greater than 0.6 to be effective passage structures for deer and elk. Ratios for both underpasses were greater than 5, thus it was surprising to document the degree of elk preference for the east underpass. Nonetheless, several studies have stressed the importance of openness and passage dimensions, as well as characteristics similar to the surrounding natural conditions, in influencing wildlife use (Reed et al. 1975, Reed et al. 1979, Foster and Humphrey 1995, Ng et al. 2004).

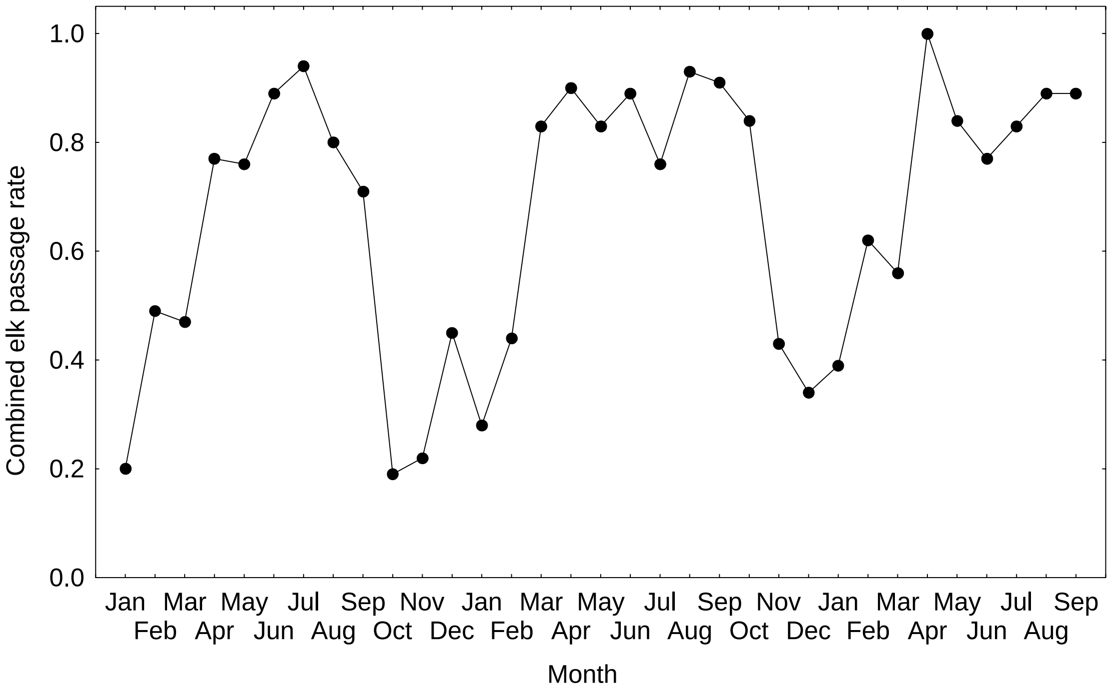

Figure 4.5. Combined mean passage rate (number of crossing elk/number of approaching elk) by month at the two Little Green Valley wildlife underpasses, State Route 260, Arizona, determined by video surveillance conducted January 2003-September 2005. Estimates for July and August 2005 reflect passage rate for the west underpass only as the east underpass system was inoperable.

The openness ratio of the east underpass was over two times higher than that of the west underpass. Most studies found that underpass width was more important than height in influencing wildlife use (Clevenger and Waltho 2000, Gordon and Anderson 2003), though little information exists on the importance of underpass length. The greater length associated with the west underpass, where elk had to traverse over two times the length of the east underpass to cross, largely accounted for the difference in openness ratios, and certainly played a large role in the observed difference in elk use and response to the two underpasses.

In addition to underpass length, we believe the concrete walls at our west underpass had a substantial influence on the lower probability of elk crossing and higher proportion of resistant behaviors compared to the east underpass. When analyzing west underpass videotapes, we frequently observed animals standing at the mouth or just inside the underpass looking upward from side to side. Though we did not document predator-prey interactions at either underpass as described by Little et al (2002), elk nonetheless appeared hypervigilant of predators potentially lurking atop the concrete walls of the west underpass. Little et al. (2002) recommended designing underpasses for prey species (e.g., elk, deer) with short, wide, and high passages to minimize predation risk; the west underpass met only the last criterion. Though several structural factors contributed to the lower elk passage rate and probability of use for this underpass, we believe that the ledge effect, the unnatural feel associated with its concrete walls, and its greater length accounted for the differences in elk response.

The reconstruction of SR 260 evolved into an effective adaptive management project when the results of our monitoring of underpass effectiveness and wildlife passage have applications elsewhere along the highway. Original plans for the Indian Gardens underpass on the Kohl's Ranch section entailed more than 40,000 ft^2 of concrete walls for soil stabilization. Based on our results, ADOT eliminated the concrete walls and increased floor width from 50 to 100 ft to enhance wildlife use of the underpass (Figure 4.6).

The unique situation of having two underpasses constructed close to each other allowed us to make an unprecedented side-by-side comparison of wildlife use and preference. Combined, these two underpasses have been successful in facilitating wildlife crossings

Figure 4.6. Indian Gardens wildlife underpass on the Kohl's Ranch section of State Route 260, Arizona, completed in March 2006. The design of this underpass was modified to eliminate concrete walls below the bridge spans for soil stabilization thus opening up the floor of the underpass (left) and preserving natural vegetation. The right photo was taken from the eastbound lanes bridge looking north toward the westbound lanes bridge. Note the escape ramp in the lower right hand portion of the right photo.

below grade. Even with limited ungulate-proof fencing (13% of the highway section), 34% of 1,298 highway crossings by 15 elk fitted with global positioning satellite collars along this section of highway were at the two underpasses (Dodd et al. 2006). Had only the west underpass been constructed, we suspect that elk use would be higher; without comparative monitoring we likely would have found the west underpass to be a highly effective structure. Structural modifications to the west underpass to increase wildlife use, as well as fencing of the entire highway section, were completed in 2007; continued video monitoring will be crucial to assessing the efficacy of these efforts.

Though uncertain whether the low (less than 0.40) initial passage rates we observed in winter 2003 with a subsequent increase to greater than 0.80 by summer reflected an ongoing adaptation process (Clevenger and Waltho 2003) or seasonal phenomenon, the subsequent two years' data suggested the latter. This was further supported by our logistic regression modeling that showed: 1) a lack of effect on underpass use by year, suggesting that elk underpass use was relatively constant among the 3 years we conducted video surveillance, and 2) season had the greatest effect on probability of underpass use. Clevenger and Waltho (2003) found relatively rapid acceptance of new underpasses by elk, achieving peak use within two years. We documented high elk passage during summer within two years of construction, facilitated by the placement of the underpass in established drainage travel routes (Foster and Humphrey 1995, Bruinderink and Hazebroek 1996, Servheen et al. 2003) and close to meadow foraging habitat.

The recurring pattern of lower elk passage rates in the winter season coincided with the time when migratory elk come off the Mogollon Rim to wintering areas adjacent to SR 260 (Brown 1990). We believe non-resident elk diluted the influence of habituated resident elk. Migratory elk do not appear to have the same propensity for habituation to underpasses as do resident elk since they typically winter south of the SR 260 corridor and are not exposed to the underpasses on a regular basis. The seasonal decline in passage rates associated with migrating elk has serious implications for achieving consistent, high, year-long underpass passage rates. This is especially the case for other completed (5) and planned (4) underpasses along SR 260 that are not close to attractive meadows that would facilitate acceptance and use (Bruinderink and Hazebroek 1996, Servheen et al. 2003). We believe additional elk-proof fencing may be needed to maximize underpass use by funneling a greater proportion of animals to underpasses and limiting options for elk crossing the highway elsewhere (Ng et al. 2004). Such fencing has proven effective in not only funneling animals to underpasses, but in reducing wildlife-vehicle collisions (Clevenger et al. 2001*b*). Along SR 260, the distribution of passage structures (1 structure/1.0 mi) limits wildlife crossings at grade without creating a continuous barrier severely limiting passage.

Our study points to the influence of traffic volume on elk use of underpasses. Servheen et al. (2003) found crepuscular peaks in timing of ungulate passage through underpasses, but also noted continued high use throughout the night corresponding to low traffic volumes, suggesting a behavioral adaptation. Mueller and Berthoud (1997) hypothesized that highways with AADT levels of 4,000–10,000 present a strong barrier that would repel animals; at more than 10,000 vehicles/day, highways become impassable to most species. On days with greater than 9,000 AADT, our weighted underpass crossings were well below expected; elk apparently adapted to crossing more than expected on relatively low (less than 6,000 AADT) traffic volume days. Nonetheless, elk did cross through underpasses, even on high traffic volume days, demonstrating the importance of underpasses in promoting highway passage (Gagnon 2006). As traffic volume on SR 260 increases, wildlife underpasses will become increasingly valuable in maintaining passage.

Our time-lapse validation showed that use of photo-beam triggers to detect approaching and crossing animals was an accurate and reliable alternative mode of VCR recording, with benefits of efficient videotape analysis time, lower costs, and increased viewer morale. Overall, our video camera systems performed reliably and remained operational more than 90% of the time; summer lightning strikes along power lines disrupted operations for a total of 2.5 months.

Video surveillance constituted a valuable means to assess and compare wildlife use at our underpasses. Though sizable, the cost of video surveillance equipment ($5,000) and power distribution ($2,000) was relatively minor compared to the cost of each underpass ($1.5–2 million) and the value of the data in evaluating their effectiveness, improving future underpass use, and reducing property loss, human injuries, and potential loss of life was great.

Using passage rate as a measure of wildlife use of passage structures is superior to frequency of passing animals alone. Passage rates determined by video surveillance are unbiased by differential wildlife densities associated with various underpasses, provide an indication of the proportion of animals that are hesitant to cross through structures, and are easier to assess than other measures such as performance indices (Clevenger and Waltho 2000, 2005). Our modeling of underpass probability of use by logistic regression yielded: 1) comparable results to passage rates without associated bias, 2) narrower CI supporting statistical inference, and 3) assessment of the effects of year, season, and design on underpass use. As such, probability of underpass use proved to be the best metric for wildlife managers to use when comparing underpass use by wildlife.

5.0 EFFECTS OF TRAFFIC VOLUME ON ELK USE OF WILDLIFE HIGHWAY UNDERPASSES [3]

5.1 INTRODUCTION

As roads around the world upgrade and expand to accommodate increasing traffic levels, the need to maintain wildlife passage while simultaneously reducing wildlife- vehicle collisions also increases. Structures that allow wildlife to safely cross the highway corridor are increasingly implemented as a mitigation measure (Romin and Bissonette 1996; Danielson and Hubbard 1998). Traffic could potentially reduce the effectiveness of these wildlife-crossing structures if wildlife respond to the visual moving fence (Bellis and Graves 1978) or audible sound fence associated with traffic passing over or below crossing structures.

Several studies have evaluated wildlife crossing structure use by wildlife (Reed et al. 1975; Reed 1981; Singer and Doherty 1985; Foster and Humphrey 1995; Clevenger and Waltho 2000, 2005; Gloyne and Clevenger 2001; Sips et al. 2002; Servheen et al. 2003; Ng et al. 2004; Dodd et al. 2006; Gagnon et al. 2006, Gagnon 2006) and some have documented animal behavior during crossings (Reed et al. 1975, Reed 1981; Ward 1982; Singer and Doherty 1985; Sips et al. 2002; Gordon and Anderson 2003; Plumb et al. 2003; Dodd et al. 2006; Gagnon et al. 2006, Gagnon 2006). Although Singer and Doherty (1985) documented decline in underpass use by mountain goats (*Oreamnos americanus*) when vehicles were present, no studies have examined the direct influence of variation in traffic on wildlife crossing behavior at wildlife underpasses. Reed et al. (1975) and Gordon and Anderson (2003) documented various behaviors of mule deer while using underpasses, assuming these behaviors were solely based on the structural attributes of the underpasses. Traffic was not documented during these studies, and as Forman et al. (2003:276) pointed out, “the response of an individual animal to the movement of different types of vehicles remains an important research frontier.”

To address this lack of understanding of traffic’s influence on wildlife, we examined the effects of traffic levels and vehicle type (tractor-trailers versus passenger cars) on the use of five underpasses by Rocky Mountain elk from June 2003 to December 2005. Our objectives were to evaluate the effect of traffic level on their use of these underpasses during two phases of attempted crossing: 1) during the period immediately prior to potential crossings, when an elk has crossed the right-of-way fence, but may still decide not to use the structure, and 2) during the period when elk are within the crossing structure when vehicles pass overhead. We focused on elk because: 1) they had a history of frequent collisions with vehicles on this highway (Dodd et al. 2006), 2) they were by far the most abundant species using these crossing structures, and 3) their size allowed behavior to be more accurately documented by video surveillance.

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[3] An early version of this section was published in the *Journal of Wildlife Management* (see Gagnon et al 2007*a)*.

5.2 MATERIALS AND METHODS

At five wildlife underpasses situated on the Preacher Canyon and Christopher Creek sections of SR 260, we used video surveillance systems consisting of four cameras triggered by infrared beams described in Section 4 and by Dodd et al. (2007*a*) and Gagnon et al. (2006) to simultaneously monitor traffic and the behavior of elk that approached within 150 ft of the underpasses (Figure 4.2). Traffic levels were determined by visual counts of vehicles recorded by the camera aimed at the roadway divided by the amount of time an elk spent in the area, until either crossing or leaving the field of view. An approach was defined as when an animal crossed the highway right-of-way fence (approximately 150 ft from the roadway) and moved toward an underpass. Passage rates were estimated by dividing the number of successful crossings by the number of approaches. Elk behavior during approach and crossings along with associated traffic levels during these times were collected from May 2003 through October 2005.

To examine the overall effect of traffic levels on passage rates we compared the proportion of animals that successfully crossed at each of four traffic volume levels, comprised of relatively equal sample sizes, to the proportion of successful crossings expected based on the relative amount of time each traffic level was experienced during attempted crossings. Our four traffic volume classes were:

- 0-2 vehicles/min.
- 2-4 vehicles/min.
- 4-6 vehicles/min.
- more than 6 vehicles/min.

Due to the herding nature of elk, we used groups of one or more elk as sampling units for this analysis. We used a chi-squared contingency table to test the hypothesis that increasing traffic levels decreased the number of crossings and in turn passage rates (Agresti 1996).

Elk using the underpasses during our study represent two population subsets: 1) resident elk that spend the entire year in the area below the Mogollon Rim that includes the study area, and 2) migratory elk, that move into the study area during migration between winter and summer ranges (Brown 1990; Dodd et al. 2006). Because elk that spend more time living along the highway year-round may have a higher tolerance for fluctuations in traffic levels, we compared passage rates during October–March, those months when both migratory and resident elk inhabited the study area, to the months of April–September when primarily resident elk were present. We used a Cochran-Mantel-Haenszel (CMH) test to determine whether season interacted with traffic effects on passage rates (Agresti 1996).

To quantify behaviors exhibited by elk approaching underpasses at different traffic levels, once elk came within 150 ft. of an underpass, we recorded the number of individuals that exhibited any of three behaviors:

- *Feeding* – elk that lowered their heads and appeared to feed for more than 30 seconds.
- *Alert-hesitation* – elk that held their heads up, were alert and immobile and appeared to be hesitating for more than 30 seconds.
- *Flight-retreat* – elk that appeared startled and rapidly moved in a direction away from the underpass.

We used contingency table chi-square to determine if each behavior was independent of traffic level (no cars, 0-2, 2-4, 4-6, more than 6 vehicles/min).

Once elk entered the underpass they could not see vehicles passing overhead and therefore sound and vibration may have been more important factors determining successful crossings. As a result, the type of vehicle passing overhead (e.g. cars versus tractor-trailers) could have different effects. To determine if vehicle type affected elk in the underpasses, we assigned three behaviors to each animal that had a passenger vehicle or tractor-trailer pass overhead:

- *No response* – elk showed no reaction to vehicles passing overhead during crossing or were already stationary prior to vehicle(s) passing overhead.
- *Delay* – elk showed hesitation while crossing at the moment a vehicle passed overhead, potentially increasing the probability that further negative stimuli could lead to an unsuccessful crossing.
- *Retreat-flight* – elk showed a retreat or flight behavior at the moment a vehicle passed overhead thereby leading to an unsuccessful crossing.

To test the hypothesis that tractor-trailers have a greater negative influence on crossings, behaviors during crossings were compared between passenger vehicles and tractor-trailers using a chi-square goodness-of-fit test (Agresti 1996). We used a CMH test to determine if effects of vehicle type were dependent on traffic level (Agresti 1996). To test the combined effects of vehicle type at intermittent and constant traffic levels we used a three-way contingency table (Agresti 1996). We estimated the conditional odds ratio of the effect of tractor-trailers versus passenger vehicles at the different traffic levels, in this case defined as the odds that elk exhibited a specific behavior at low traffic levels divided by the odds of that same behavior at high traffic levels (Agresti 1996).

5.3 RESULTS

We analyzed approximately 233 hours of elk behavior and documented 805 groups that included 2,359 individual elk. Of these, 783 groups of elk consisting of 2,086 individuals crossed the ROW fence and came within the 150-ft. zone constituting an approach. When combined across all underpasses, traffic levels had a statistically significant effect on elk passage rates (χ^2 =16.64, df = 4, P = 0.005), however, this was driven by significant effect of traffic at the 0–2 and the 2–4 vehicles/minute categories, which contributed 82% of the overall $\chi 2$ statistic (Table 5.1).

Of the 2,086 elk that approached the underpass, behaviors varied with traffic levels (Figure 5.1). The proportion of elk that showed a heads-up alert/hesitation response increased with traffic (χ^2 = 52.98, df = 4, $P < 0.001$), as did the number of elk showing a flight response away from the underpass, although the proportion showing flight was usually relatively low, not exceeding 0.20 (χ^2 = 27.42, df = 4, $P < 0.001$). Elk feeding behavior fluctuated with traffic volume level (Figure 5.1), increasing sharply to almost 50% at very low traffic levels and dropping below 30% at the three highest traffic levels (χ^2 = 81.4, df = 4, $P < 0.001$).

Table 5.1. Number of successful and unsuccessful elk crossings and passage rates (no. crossing/no. approaching) by elk groups observed by video surveillance at five wildlife underpasses along State Route 360, Arizona, at varying traffic levels.

	Traffic volume level (vehicles/min)				
Parameter	0	1–2	2– 4	4–6	>6
Successful crossings	42	191	120	57	62
Unsuccessful crossings	23	133	39	21	25
Passage rate	0.65	0.59	0.75	0.73	0.71

Vehicles passed directly overhead of individual elk during 785 crossings: 634 involved passenger vehicles, 147 tractor-trailers. Overall responses by elk while tractor-trailers passed overhead (63.3%) occurred more frequently than when passenger vehicles passed overhead (44.9%) (χ^2 = 13.85, df = 1, $p < 0.001$). There did not appear to be a difference in the number of delays exhibited by elk for passenger vehicles or tractor-trailers (26.5% and 27.6%, respectively). However, tractor-trailers were associated with elk flight from the underpasses 36.7% of the time while passenger vehicles caused flight 17.2% of the time (χ^2 = 25.56, df = 1, $P < 0.001$). This flight response was dependent on traffic level (CMH = χ^2 = 27.27, df = 1, $P < 0.001$). When traffic levels were below four vehicles/minute, tractor-trailers were associated with a greater percentage of flight responses than were passenger vehicles (χ^2 = 44.57, df = 1, $P < 0.001$). When traffic levels were relatively continuous (more than 4 vehicles/minute) flight behavior was not different for passenger vehicles and tractor-trailers (χ^2 = 0.008, df = 1, P = 0.930; Table 5.2). Conditional odds ratios indicated that tractor-trailers were five times more likely than passenger vehicles to cause a flight response when traffic levels were less than 4 vehicles/min compared to when they were more than 4 vehicles/minute.

Table 5.2. Number of individual elk exhibiting flight responses while passenger vehicles and semis passed overhead at low and high traffic levels during attempted crossings at five wildlife underpasses along State Route 260 in central Arizona, 2003 – 2005.

Vehicle type	Traffic volume level					
	< 4 vehicles/min			> 4 vehicles/min		
	Flight	Total elk	Proportion	Flight	Total elk	Proportion
Passenger	57	344	0.17	52	289	0.18
Tractor-trailer	42	82	0.51	12	65	0.19
All	99	426	0.23	64	354	0.18

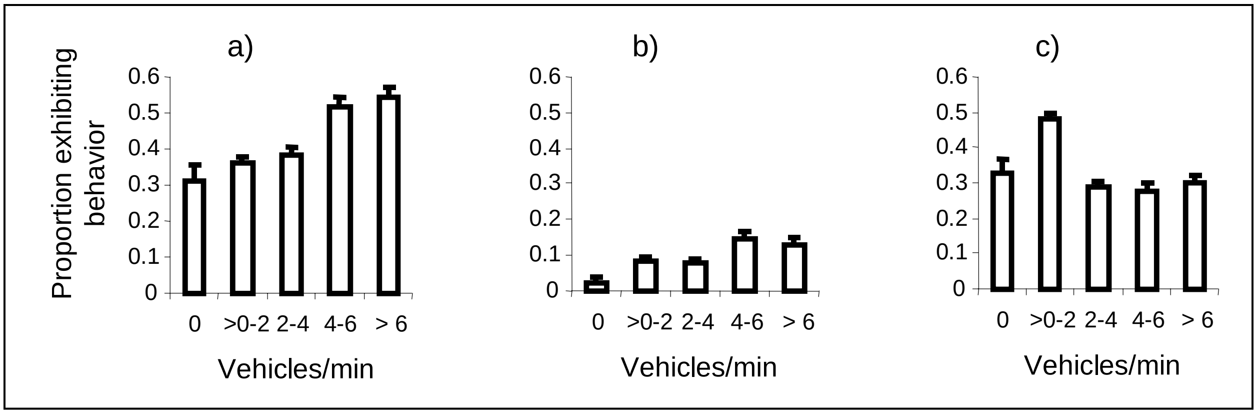

Figure 5.1. Proportion (±SE) of individual elk exhibiting: a) alert-hesitation, b) flight-retreat, and c) feeding behavior when observed approaching five underpasses along State Route 260, Arizona, at varying traffic levels. We recorded elk on video surveillance systems at the five underpasses.

The effect of traffic on passage rates by elk was dependent upon season (CMH = χ^2 = 9.12, df = 1, $P < 0.005$) with minimal effects of traffic in the winter and summer (χ^2 = 8.1, df = 4, $P = 0.09$) and stronger effects of traffic during migratory seasons (χ^2 = 16.76, df = 4, $P = 0.002$). These passage rates showed the greatest drop for both migratory and non-migratory seasons when traffic levels were low (between 0-2 vehicles/hour), however this drop was even greater during the migratory months (Figure 5.2).

5.4 DISCUSSION

Across the traffic levels we monitored, elk passage rates were not reduced compared to periods when no traffic was present, except at relatively low traffic levels. This effect was evident in overall passage rates, in the stronger effects of tractor-trailers versus automobiles and in the comparison of passage rates across seasons. In all cases, this may have been due to elk responding to the "shock factor" created by the sudden sound and visual stimulation of a single vehicle passing by during periods of relative quiet compared to the relatively continuous noise stream that passing vehicles create (Forman et al. 2003).

The greatest increases in traffic noise occur up to approximately 10,000 vehicles/day. (Ellenberg et al. 1981; Reijnen et al. 1995; Forman et al. 2003). From 1 to 10,000 vehicles/day, sound increases to 70 dB (A) while an increase from 12,000 to 36,000 vehicles /day only increases sound one to two dB (A) (Ellenberg et al. 1981). The average annual daily traffic during this study was approximately 8,000 vehicles/day, but fluctuated greatly depending on day of week, allowing elk and other wildlife along this stretch of roadway to experience the greatest fluctuations in sound levels associated with varying traffic. In spite of this, the elk in our study crossed through underpasses at high traffic levels at rates comparable to those when no traffic was present and those that were not repelled crossed through quickly, with little to no hesitation. This agrees with a concurrent study of the effects of traffic level on elk highway crossings (Gagnon 2006), where some elk crossed the highway at very high traffic levels, although they made long distance movements and traveled at a faster rate to do so.

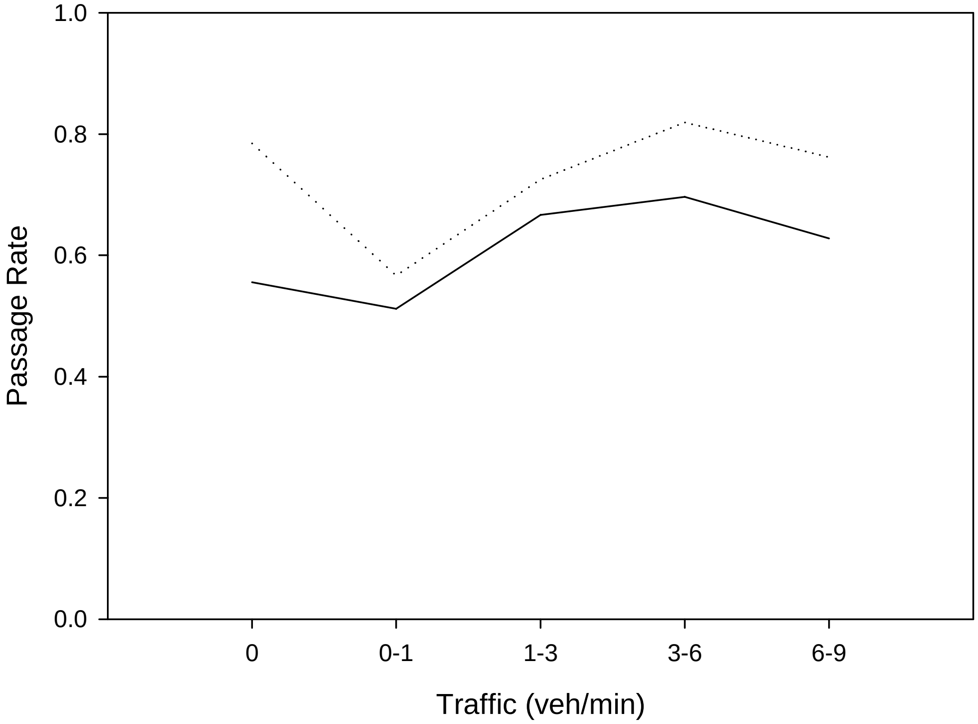

Figure 5.2. Mean passage rates for elk during winter and summer (solid line) and fall and spring migration period (dotted line) through five wildlife underpasses at varying traffic levels along State Route 260, Arizona, 2003-2005.

Elk may increase their use of underpasses over time as they become familiar with them and elk could likewise become habituated to the effects of traffic. As a result, elk living near highways year-round may be less sensitive to traffic than animals that migrate through seasonally. Consistent with this hypothesis, passage rates were lower during the months of October through March, when a greater proportion of migratory elk were in the study area. This suggests that migratory elk, having spent less time in the vicinity of roads, may be more sensitive to traffic. If so, migratory elk may be more likely to retreat from underpasses and potentially cross the highway in other places, increasing the probability of collisions with vehicles. This hypothesis is consistent with observations that elk-vehicle collisions reached higher levels during migration periods along this same stretch of roadway (Dodd et al. 2006) and, as discussed in Section 4 and Dodd et al. (2007*a*), that spring and fall months showed dramatic drops in passage rates at two of the wildlife underpasses studied here.

Much of the behavior associated with elk underpass crossings and non-crossings may be driven by the behavior of a "lead cow" or dominant bull. In many of the recorded crossings, the lead elk showed initial hesitation, but once that animal moved through the underpass the remainder of the herd followed without hesitation. Another common scenario during the mating season was when a bull, or several bulls, either herded or led a group of cows through the underpass. As a result, the sensitivity to underpass and/or traffic of a relatively small subset of the population, lead cows and dominant bulls, may have important repercussions for the remainder of elk in an area. If those animals are willing to cross through an underpass to obtain preferred resources, the entire herd may benefit. Alternatively, if the lead elk retreats from underpasses as a result of traffic and crosses the roadway at other locations, the rest of the herd may be at risk of higher interaction with vehicles.

Elk in this study exhibited various responses to traffic, including increased alertness and flight responses as traffic levels increased. These behaviors, although infrequent enough to not significantly reduce passage rates at most traffic levels, could cause some animals to attempt to cross the highway at other points, thereby increasing the possibility of elk-vehicle interactions. While the reduced passage rates and relatively low levels of flight caused by traffic may have little overall negative impact on the population's access to its habitat, even rare events that increase the chance of a deadly or costly accident are unacceptable. While flight from the area obviously leads to a failed crossing, delays and hesitations may also increase the probability of encountering negative stimuli that lead to an unsuccessful crossing. Humans, vehicles, dogs, predators or other wildlife could startle elk that are slowly making their way through an underpass (Little et al. 2002; Clevenger and Waltho 2005).

The feeding behavior we recorded in the vicinity of the underpasses can represent different motivational states: 1) feeding along the highway with no intention of crossing, or 2) displacement behavior of elk hesitant to use underpasses. The former may be more likely when no vehicles were present and may explain why passage rates were slightly lower when no vehicles were present compared to periods when more than two vehicles/min were present. A study of GPS-collared elk along the same stretch of roadway showed that elk shifted their distributions closer to the highway when traffic levels were less than or equal to 100 vehicles/hour (Gagnon 2006), suggesting that habitat near the road is utilized more for behaviors like feeding at low traffic levels.

Once elk entered the underpass, response to traffic was more likely due to sound or vibration than the visual stimulation encountered prior to crossing. Tractor-trailers passing overhead were associated with flight behavior twice as often as passenger vehicles. Their influence is likely due to the sound created by larger vehicles; a heavy truck passing by on the road produces approximately 10 dB (A) more noise than passenger vehicles (Lee and Fleming 1996). In our study, the influence of tractor-trailers was more evident when intermittent traffic was present, perhaps due to the overall increase in sound and vibration experienced compared to relative quiet versus the same sound level against a background of sound and vibration associated with a more continuous flow of traffic.

Although overall passage rates differed among the five structures we studied, at any one structure, passage rates at high and low traffic levels did not differ, suggesting that design and placement of crossings far outweigh negative effects of traffic. Attributes and proper placement of individual underpasses are key to the success of a wildlife underpass (Reed et al. 1975; Beier and Loe 1992; Foster and Humphrey 1995; Clevenger and Waltho 2000, 2005; Forman et al. 2003; Dodd et al. 2006; Gagnon et al. 2006) and since traffic levels are likely uncontrollable, this increases the need for proper underpass design and placement.

One critical effect of traffic that we could not address in this study was whether traffic levels affected the overall probability that elk would approach underpasses near enough to be recorded by our cameras. Gagnon (2006) showed that elk along this highway moved farther away as traffic levels increased, suggesting that the overall approach rate at the underpasses may have been lower at higher traffic levels. If so, high traffic may lengthen the amount time animals require to locate and habituate to crossing structures. Given this effect, reducing noise and visual stimuli at underpasses could potentially guide animals to crossing structures by creating a “gap” in the sound and visual “fence” that traffic creates. These modifications could also reduce the sound of vehicles passing directly overhead, particularly tractor-trailers, thereby reducing the probability that elk will retreat from an underpass and cross the highway at another location where they could pose a danger to motorists.

Given that higher traffic levels did not significantly reduce elk passage rates at the wildlife underpasses we studied, these structures remain viable means to reduce the impact of highway barrier effects on wildlife populations even when traffic is relatively high. However, even the relatively small effects of traffic on hesitancy and flight responses by elk could cause some animals to attempt crossing the highway at other points, thereby increasing the probability of elk-vehicle collisions. As a result, methods to reduce the visual and auditory stimuli associated with traffic in the area of wildlife crossing structures, especially at low and intermediate traffic levels may be needed.

To assess whether such measures would be effective, two avenues of further research should be undertaken. First, experiments should be undertaken to determine whether elk that are repelled from underpasses by traffic indeed cross the highway at other places, risking interaction with vehicles, or instead return to use underpasses at times with different traffic levels. Especially important is whether migratory animals that are less familiar with crossing structures are more likely to cross the highway elsewhere and thereby increase the potential for elk-vehicle collisions during migratory periods. Second, given that elk move away from the highway at higher traffic levels (Gagnon 2006) and that individuals flee from traffic at underpasses under certain conditions, experiments assessing the response to modifications that reduce visual and sound stimuli at crossing structures, in essence creating holes in the visual “moving fence” or the audible “sound fence” would elucidate whether and to what degree the effectiveness of wildlife-crossing structures could be increased by these measures.

6.0 ASSESSMENT OF ELK HIGHWAY PERMEABILITY USING GLOBAL POSITIONING SYSTEM TELEMETRY[4]

6.1 INTODUCTION

Though numerous studies have alluded to highways' barrier effects on wildlife (e.g., see Forman et al. 2003), few have generated quantitative data on animal passage rates, particularly in an experimental context (e.g., pre- and post construction). Many studies have instead focused on the efficacy of passage structures in maintaining passage (Clevenger and Waltho 2003, Ng et al. 2004) or relied on modeling to assess ability to cross (Singleton et al. 2002).

Researchers have used mark-recapture trapping to measure the habitat fragmentation that highways create for relatively low-mobility small mammals (Swihart and Slade 1984, Conrey and Mills 2001, McGregor et al. 2003), but such assessments for larger, far-ranging species have been limited by the lack of cost-effective techniques. Paquet and Callaghan (1996) used winter track counts to determine highway passage rates by wolves. VHF radio telemetry has been used to assess wildlife movements and response to highways, often pointing to avoidance of highways and roads (Brody and Pelton 1989, Rowland et al. 2000) but seldom directly addressing passage as Gibeau et al. (2001) did for grizzly bears.

Global Positioning System (GPS) telemetry has become an increasingly popular, cost-effective, and reliable means of collecting data on wildlife movement (Rodgers et al. 1996, D'Eon et al. 2002,). With continuous automated tracking at set time intervals, reduced observer bias (compared to VHF telemetry), and the ability to collect large datasets, GPS telemetry has revolutionized the study of wildlife movement. GPS telemetry is increasingly being used to address heretofore-difficult questions (e.g., Anderson and Lindzey 2003) and holds tremendous potential to facilitate highway passage assessment. Applications of GPS telemetry to assess wildlife highway permeability have been limited to grizzly bears (Waller and Servheen 2005), black bears (*Ursus americanus*; McCoy 2005), and caribou (*Rangifer tarandus*; Dyer et al. 2002).

We investigated the distribution and movements of Rocky Mountain elk along the section of SR260 while it was being reconstructed, which allowed us to compare animals' ability to cross the highway sections while they were in various stages of reconstruction. Our objective was to develop quantitative measures of highway passability, or permeability using GPS telemetry. We used GPS equipment to capture data on spatial crossing patterns of elk, their crossing frequency, and their distribution in relation to the highway and compared them to random patterns we generated. We assessed the influence of habitat on elk distribution and crossing patterns and identified how GPS crossing data can help achieve effective use of wildlife passage structures.

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[4] An earlier version of this chapter was published in the *Journal of Wildlife Management* (see Dodd et al. 2007*b*)

6.2 METHODS

6.2.1 Elk Capture and GPS Collars

We captured elk at 10 sites spaced an average of 1.6 mi (±0.4 SE) along the entire 17-mi length of SR 260. We captured 29 elk in net-covered Clover traps (Clover 1954) baited with salt and alfalfa hay, with all traps located within 1,000 ft of the highway corridor (Figure 6.1). We used a 40 × 40-ft remote-triggered drop net to capture 4 others. We physically restrained the elk, blindfolded them, tagged their ears, and fitted them with GPS receiver collars (Figure 6.1). We timed trapping to target resident elk to maximize yearlong acquisition of GPS fixes near the highway.

We fitted the elk with two models of GPS receiver collars made by Telonics, Inc. of Mesa, Arizona. We used 23 TGW-3600 store-on-board collars of which we programmed 19 to receive a fix every two hours and four were programmed to obtain fixes every 1.5 hours from 5:00p.m. to -9:00a.m. (12 fixes) and one fix at noon.. We also used five TGW-3680 collars that we programmed to receive fixes every four hours and had ARGOS satellite uplink capabilities for rapid recovery of data that was used in our early adaptive management activities. All collars had VHF beacons, mortality sensors, and programmed release mechanisms to allow recovery.

Figure 6.1. Cow elk caught in a Clover trap (left) and being fitted with a GPS receiver collar, along State Route 260, Arizona.

6.2.2 GPS Accuracy Validation

We assessed the GPS fix accuracy of the collars by placing them 3–5 ft above ground at 39 sites for one to four days, with fixes acquired every four hours (Dussault et al. 2001, D’Eon et al. 2002, Di Orio et al. 2003). We located 13 sites each in ponderosa pine forest, sparse pinyon-juniper interspersed in chaparral, and meadows to assess the influence of canopy on accuracy (Rempel et al. 1995); we placed the collars on a range of slopes in the non-meadow habitats. At each site, we determined a known position derived from a differentially corrected average of at least 80 fixes obtained by a Trimble Geo Explorer II unit made by Trimble Navigation Ltd. of Sunnyvale, California, with accuracy assumed to be less than 3 ft. (D'Eon et al. 2002). We computed the deviation from the known position for each sample fix and determined whether the fix was a three-dimensional (3-D) or two-dimensional (2-D) fix. We also compared the number of fixes acquired at our sites to the possible fixes for the period the collars were at the site.

6.2.3 GPS Data Analysis of Elk Movements

We employed ArcGIS Version 8.3 Geographic Information System (GIS) software made by Environmental Systems Research Institute (ESRI) of Redlands, California, to analyze the GPS data. We divided our study site into 190 sequentially numbered 0.1-mi segments (Figure 6.2) corresponding to the units used by ADOT for tracking wildlife-vehicle collisions and highway maintenance. We used these segments to quantify highway approaches and crossings by the collared elk. We established buffer zones of varying distances from the highway to assess GPS fix distribution and to determine elk highway approaches, including: 1) less than 0.06 mi, 2) 0.06-0.15 mi, 3) 0.15–0.30 mi, and 4) 0.30–0.60 mi.

To determine highway crossings, we drew lines connecting consecutive GPS fixes (Figure 6.2). We inferred crossings where lines between fixes crossed the highway through a given segment (Figure 6.2). We used Animal Movement ArcView Extension Version 1.1 software to assist in determining elk crossings (Hooge and Eichenlaub 1997). We compiled crossings by individual animal, highway segment, associated distance between and distance from the highway for the two consecutive crossing fixes, direction of travel, date, and time. We calculated crossing rates for individual elk by dividing the number of crossings by the number of days a collar was worn.

We calculated passage rates for the collared elk, which served as our relative measure of highway permeability. We considered an approach to be when an elk traveled from a point outside the 0.15-mi buffer zone to a point within it (Figure 6.2), as determined by successive GPS fixes. Our approach zone corresponded to the road-effect zone where elk are 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 treated successive GPS fixes within 0.15 mi of SR 260 as a single approach. If an elk directly crossed the highway from a point beyond 0.15 mi, it was counted as an approach. We calculated passage rates for each elk as the proportion of highway crossings to approaches during the period they were instrumented with GPS collars. Our analysis excluded fixes within 0.15 mi of the highway that occurred between 9:00a.m. and 5:00p.m. without an associated crossing and any approach where successive fixes did not exceed two times our mean GPS fix accuracy distance (±33 ft; see results); we considered these data more reflective of elk bedding versus highway approach or crossing behavior.

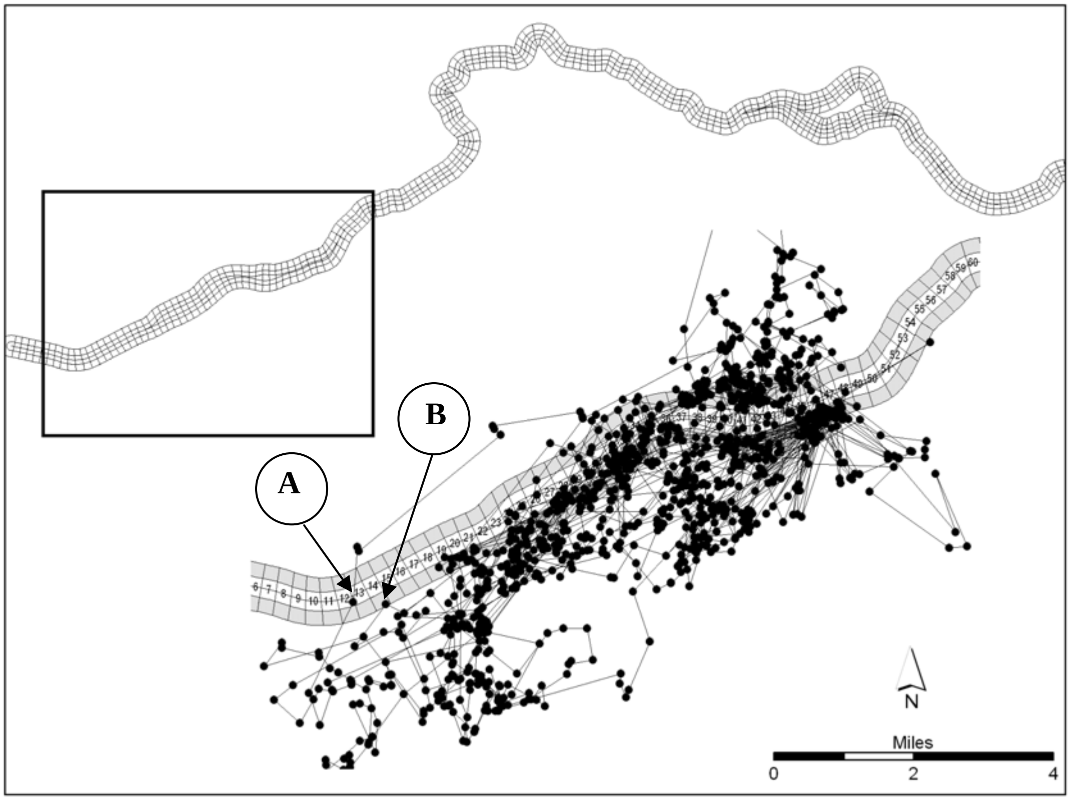

Figure 6.2. Highway segments (0.10 mi) delineated along State Route 260, Arizona, used to compile highway crossings by elk, and the 0.15-mi distance buffer in which approaches to the highway were determined. The expanded section shows GPS locations for cow elk no. 2, and lines between successive fixes 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.

We compared the elk crossing and passage rates of three different reconstruction classes:

- the section where highway reconstruction was completed at the onset of the study (Preacher Canyon),
- sections where reconstruction was ongoing (Kohl's Ranch, Christopher Creek), and
- control sections (Little Green Valley, Doubtful Canyon).

We derived values for individual elk approaching and crossing on each highway section and pooled them by reconstruction class.

We used a GIS vegetative layer that was based on terrestrial ecosystem analysis developed from unpublished data provided by the Tonto National Forest to calculate the area comprised of 5 vegetative types: 1) chaparral, 2) pinyon-juniper, 3) ponderosa pine, 4) mixed conifer, and 5) riparian-meadow. We calculated the area and relative proportions of the vegetative types within: 1) the home ranges of the individual elk, and 2) our 0.6-mi buffer zone of SR 260. We determined the frequency and proportion of total elk GPS fixes occurring within each vegetative type using this GIS vegetative layer. We delineated the home range of each elk by creating a minimum convex polygon (MCP) that connected the animal's outermost GPS fixes and had all its GPS fixes within the polygon (White and Garrott 1990).

6.2.4 Statistical Analysis

We performed all statistical tests using the program STATISTICA Version 5.5 (Statsoft, Inc. 1999). We considered results significant at $P \leq 0.05$. We reported mean values with ± 1 SE.

We used a Kolmogorov-Smirnov test (Clevenger et al. 2001) to test the hypothesis that our observed spatial crossing distribution (by 0.10-mi segments) did not differ from a randomly generated crossing distribution. This test is sensitive to both the difference in ranks and shape of the distributions (Statsoft, Inc. 1999).

We tested the hypotheses that our observed distribution of elk relative to distance from SR 260 and the frequency of crossings did not differ from a set of randomly generated locations and highway crossings (Dyer et al. 2002, Waller and Servheen 2005). We used two separate analyses to test these hypotheses. Within the MCP home range of each elk, we generated the same number of random points as successful GPS fixes (Figure 6.3). We determined the distribution of random points relative to the buffer zones around SR 260 in the same manner as those determined for GPS telemetry.

Within a subset of the MCP home range corresponding to the 0.6-mi buffer zone around SR 260 for each elk, we generated an equivalent number of random line segments as lines between GPS fixes obtained from telemetry (Figure 6.3) using Random Sample Generator Version 1.1 software published by the Minnesota Department of Natural Resources, St. Paul, Minnesota. We constrained random line segments to 0.6 mi or less in length to approximate actual elk movements. We calculated the frequency of random highway crossings for each elk, where random line segments intersected SR 260, using ESRI's ArcMap (Version 9.1).

We used analysis of variance (ANOVA; Hays 1981) to compare differences between means for cow and bull elk crossing, approach, and passage rates, and random versus observed highway-crossing frequency. We employed ANOVA to test the null hypothesis that no differences in elk crossing and passage rates existed as a function of highway reconstruction class among the control sections and those where reconstruction was complete or ongoing. Where we obtained significant ANOVA results among classes, we conducted post hoc pairwise comparisons using a Tukey test for unequal sample sizes (Statsoft Inc. 1999).

For our GPS accuracy validation, we assessed mean deviations from known locations among vegetation types by ANOVA. We made pairwise comparisons of accuracy among vegetation types using a Tukey test for unequal sample sizes. We compared 3-D and 2-D fix accuracy with a *t*-test for independent samples.

We employed chi-squared tests to compare observed versus expected values for elk GPS fix distribution by distance zone from the highway versus the random distribution (expected).

We also used chi-squared tests to determine if the observed proportion of GPS fixes within each vegetation type occurred in proportion to the availability of each vegetation type found within the 0.6-mi zone around SR 260 (Jones and Hudson 2002). We used Spearman rank order correlation to investigate the association between the frequency of elk GPS crossings by 0.1-mi segments and distance to the nearest riparian-meadow habitat.

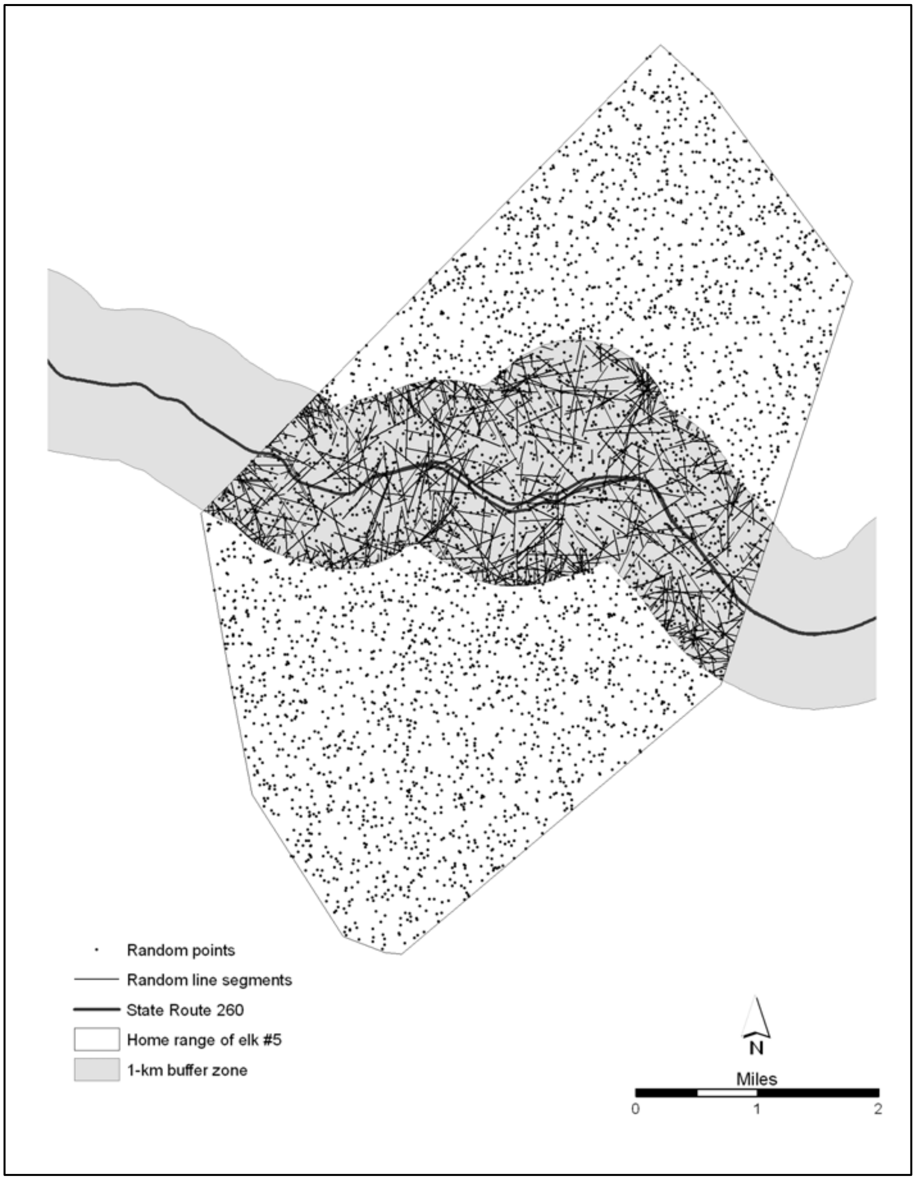

Figure 6.3. Minimum convex polygon (MCP) home range (White and Garrott 1990) adjacent to the study area for bull elk no. 5 in which we generated the same number of random points (dots) as successful Global Positioning System (GPS) fixes (n = 3,815) to compare distribution. Within the 0.6-mi buffer zone subset of the MCP home range (shaded), we generated the same number of random line segments (lines) as lines between GPS fixes (n = 823); from these random lines, we calculated the frequency of random highway crossings for each elk where random line segments intersected SR 260. We conducted GPS telemetry May 2004–April 2004.

6.3 RESULTS

We put GPS receiver collars on 33 elk (25 F, 8 M): 23 elk in May 2002 (19 in Clover traps and 4 by drop net) and 10 in Clover traps between July 2002 and January 2004, as collars became available following 11 deaths; we also installed four new collars in October 2003. We recovered all collars and downloaded GPS data by April 2004.

Our GPS collars were affixed to elk an average of 412.9 days (±39.1; range = 50–684 days). We acquired 101,506 GPS fixes, representing a 70.1% fix success (range = 23.1–100.0%). We obtained a mean of 3,075.9 fixes/elk (±378.3; range = 344–7,332 fixes/elk); 67.9% of our fixes were 2-D (range = 22.4–91.7%).

6.3.1 GPS Fix Accuracy

In our accuracy validation we acquired 608 of 619 possible GPS fixes (98.2% fix success) at our 39 test sites; of the successful fixes, 62.8% were at least within 33 ft of the known locations, and 86.5% deviated no more than 65 ft from known positions. Our combined fixes deviated from known locations an average of 31.5 ft (±0.6). Our 3-D fixes (29.2 ft ±1.6, $n = 426$) were more accurate ($t_{606} = -2.52$, $P = 0.012$) than 2-D fixes (36.7 ft ±3.0, $n = 182$). We found that accuracy differed among vegetation types for 2-D and 3-D fix types combined (ANOVA $F_{2,605} = 5.25$, $P = 0.006$) and for 2-D fixes separately ($F_{2,179} = 4.79$, $P = 0.010$), but accuracy did not differ when we considered only 3-D fixes ($P = 0.286$). Fixes we obtained in meadows deviated from known locations an average of 24.0 ft. (±1.6), pinyon-chaparral 32.8 ft (±2.3), and ponderosa pine 35.8 ft (±2.6). For both fix types combined, our meadow fixes were more accurate than those in ponderosa pine ($P = 0.006$), and our 2-D meadow fixes were more accurate than those we obtained in both pinyon-chaparral ($P = 0.034$) and ponderosa pine ($P = 0.032$).

6.3.2 Elk Highway Movements

46,162 (45.5%) of our fixes were within 0.6 mi of the highway. On average, we obtained 3.4 fixes/day/elk (±0.4)from within 0.6 mi of the highway, though cows were there four times as frequently as bulls (ANOVA $F_{1,31} = 10.91$, $P = 0.002$; Table 6.1). Elk came within 0.15 mi of the highway (approach distance) on 13,755 occasions with a mean of 416.8 fixes/elk (±119.8); we located cows within 0.15 mi of SR 260 nearly 6 times as frequently as bulls (Table 6.2).

Whereas only a quarter of the random points within MCP home ranges fell within 0.6 mi of SR 260 (791.1 fixes/elk ± 103.2), nearly half the observed GPS fixes occurred there (1,801.3 fixes/elk ± 311.3; Figure 6.4). An average of 79% more GPS fixes were from our four buffer zones within 0.6 mi of SR 260 compared to random (Figure 6.4); we rejected the hypothesis that there was no difference in the distribution ($\chi^2 = 520.8$, df = 3, $P < 0.001$).

Our collared elk crossed SR 260 3,057 times (Figure 6.5), with a mean of 92.6 crossings/elk (±23.5; range = 1-691 crossings/elk; Table 6.1). The number of different elk crossing at each highway segment ranged from 0–8 elk and averaged 3.3 elk. On average, elk crossed 0.22 times/day (±0.04), with cows crossing more than 4.5 times as frequently as bulls ($F_{1,31} = 6.07$, $P = 0.019$; Table 6.2). Overall, 68.1% (n = 2,083) of our crossings were determined for intervals of 4 hours or less between GPS fixes. Our mean elk crossing distance associated with GPS fix intervals of 4 hours or less was 2,118.5 ft (±164.7).

Table 6.1. Highway crossings by section along State Route 260, Arizona, of 33 elk fitted with Global Positioning System (GPS) telemetry collars, including the length and construction status of each section, number of elk that crossed the highway within each section, and mean passage rate. We conducted GPS telemetry May 2002–April 2004.

Highway section	Status	No. elk	Elk crossings No.	Elk crossings %	Crossings/ mi	Passage rate[a] Mean	(±SE)
Lion Springs[b]	Control	4	24	0.8	12.1		
Preacher Canyon	Complete 2001	15	1,298	42.4	457.2	0.43	(0.15)
Little Green Valley	Control	8	132	4.3	53.5	0.81	(0.22)
Kohl's Ranch	Ongoing	13	212	6.9	63.5	0.93	(0.29)
Doubtful Canyon	Control	8	292	9.5	105.1	0.95	(0.23)
Christopher Creek	Complete 2003[c]	14	1,070	35.0	216.8	0.79	(0.09)
All		33	3,057	100.0	166.2	0.67	(0.08)

[a] Passage rate = highway crossings/approach
[b] Only partial coverage of the Lion Springs section (planned for reconstruction after 2010)
[c] All 4 lanes were not opened to traffic until 2004, 8 months after reconstruction was complete

We rejected the hypothesis that the spatial frequency distribution of crossings occurred randomly (Kolmogorov-Smirnov test, $d = 0.01$, $P < 0.001$); rather crossings exhibited a strongly aggregated pattern (Figure 6.5). Our highest crossing frequency occurred on the Preacher Canyon section (457.2/mi), followed by the Christopher Creek section (216.8/mi; Table 6.1). Combined, we found that all other sections exhibited relatively low crossing frequencies (fewer than 65 crossings/mi; Table 9), though well-defined peaks above the overall crossings/segment mean (16.4) also occurred near meadow-riparian habitats on the Kohl's Ranch and Doubtful Canyon sections (Figure 6.5).

Our random highway crossing analysis identified 4,938 crossings, with a mean frequency of 149.6 crossings/elk (±27.6). The length of random crossing lines averaged 2,025.0 ft (±42.3), closely approximating the mean distance elk traveled in four-hour intervals between GPS fixes (2,118.5 ft ±164.7). The mean random highway crossing frequency was greater than our observed frequency of elk crossings ($F_{1, 31} = 2.31$, $P = 0.021$). We found that observed highway-crossing rates did not differ among reconstruction classes ($P = 0.478$; Table 6.3).

Our mean elk passage rate across SR 260 was 0.67 crossings/approach (±0.08) and ranged from 0.43 to 0.95 crossings/approach on individual highway sections (Table 6.1). We found differences in elk passage rates among the three highway reconstruction classes (ANOVA $F_{2, 49} = 8.42$, $P = 0.005$). The passage rate for elk crossing the completed Preacher Canyon section (0.43 crossings/approach ±0.15) was half the rate of elk crossing the highway along control sections ($P = 0.037$) and sections under reconstruction ($P = 0.011$; Table 6.3). The passage rate for elk using control sections did not differ from those using sections where reconstruction was ongoing ($P = 0.873$; Table 6.3).

Table 6.2. Mean values we calculated by elk class for highway crossing, approach, and passage rate parameters, and minimum convex polygon (MCP) home ranges determined from Global Positioning System (GPS) telemetry along State Route 260, Arizona; and results of ANOVA (all df = 1, 31) tests of differences in means between cows and bulls. We conducted GPS telemetry May 2002–April 2004.

	Mean value by elk class (±SE)			ANOVA
Parameter	All[a]	Cows[b]	Bulls[c]	cow vs bull means
No. highway crossings	92.6 (23.5)	112.0 (29.9)	32.1 (12.2)	$F = 2.20$, $P = 0.148$
Highway crossings/day	0.22 (0.04)	0.28 (0.05)	0.06 (0.02)	$F = 6.07$, $P = 0.019$
GPS fixes/day ≤0.6 mi of highway	3.40 (0.45)	4.14 (0.51)	1.05 (0.22)	$F = 10.92$, $P = 0.002$
GPS fixes ≤0.15 mi of highway	416.8 (119.8)	521.5 (152.8)	89.6 (19.8)	$F = 2.50$, $P = 0.124$
GPS fixes ≤0.06 mi of highway	135.4 (46.3)	171.3 (59.5)	23.1 (7.7)	$F = 1.94$, $P = 0.174$
Highway approaches/day	0.48 (0.09)	0.55 (0.12)	0.21 (0.03)	$F = 2.10$, $P = 0.158$
Passage rate (crossings/approach)	0.67 (0.08)	0.71 (0.09)	0.56 (0.13)	$F = 0.60$, $P = 0.444$
MCP use area (mi2)	28.2 (4.3)	25.3 (4.3)	37.5 (30.1)	$F = 1.52$, $P = 0.227$

[a] $n = 33$ [b] $n = 25$ [c] $n = 8$

6.3.3 Habitat and Elk Movements

We found the distribution among the five vegetative types of the elk GPS fixes within 0.6 mi of SR 260 was approximately the same as that of the total habitat (all chi-squared test $P > 0.992$; Table 6.4) with the exception of riparian-meadow habitat ($\chi^2 = 545.9$, $P < 0.001$). Although riparian-meadow habitat comprised an average of only 0.6% of elk MCP home ranges and 4% of the area adjacent to SR 260, 18% of elk GPS fixes occurred within this habitat (Table 6.4). We found a strong negative correlation between elk crossing frequency for 0.1-mi segments and distance to the nearest riparian-meadow habitat ($r_s = -0.714$, $n = 190$, $P < 0.001$).

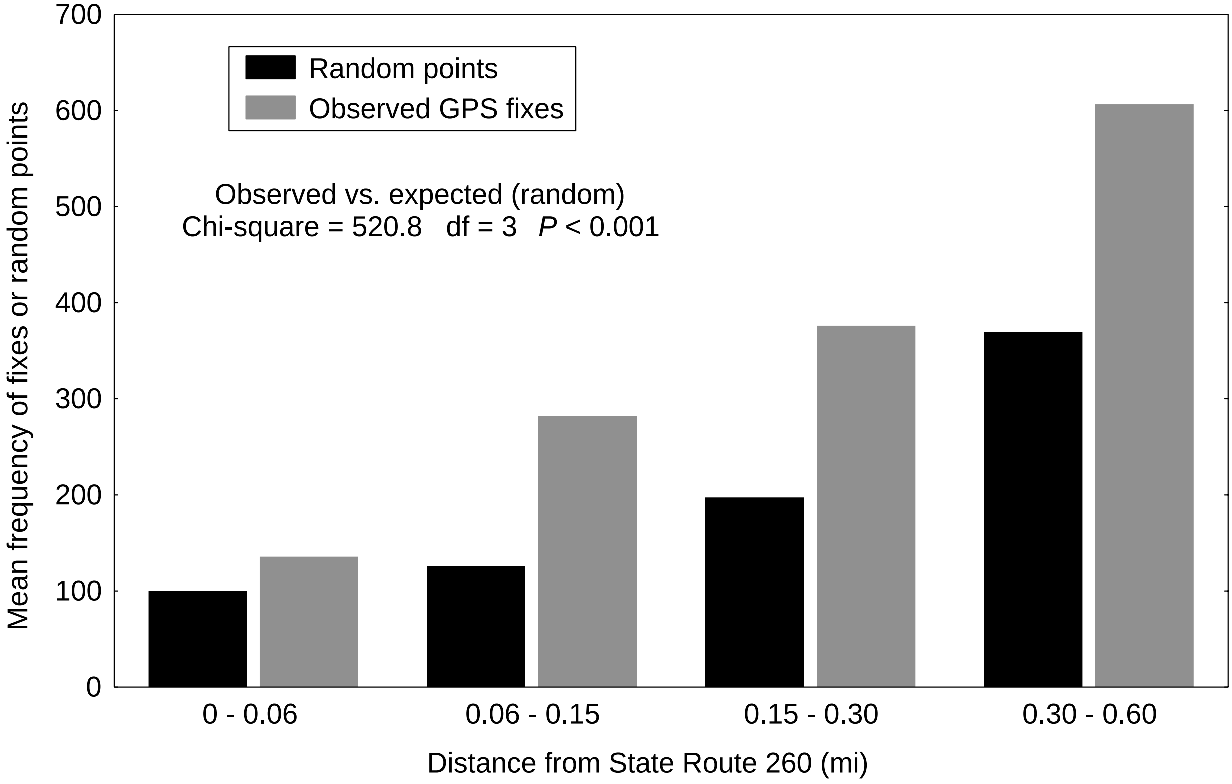

Figure 6.4. Mean frequency of observed Global Positioning System (GPS) fixes and random points generated for 33 elk fitted with GPS receiver collars that occurred in buffer zones within 0.6 mi of State Route 260, Arizona. We conducted GPS telemetry May 2002–April 2004.

Table 6.3. Mean crossings/day and passage rates (crossings/approach) calculated by highway reconstruction class along State Route 260, Arizona, from 33 elk fitted with Global Positioning System (GPS) telemetry collars. We conducted GPS telemetry May 2002–April 2004. Letters denote significant differences for Tukey test pairwise construction class comparisons for significant ANOVA.

Reconstruction class	No. elk	Crossings/day	±SE	Passage rate[a]	±SE
Control	15	0.22 A	0.11	0.88 A	0.16
Under reconstruction	22	0.26 A	0.05	0.84 A	0.12
Reconstruction complete	15	0.27 A	0.09	0.43 B[b]	0.15

[a] Passage rates differ among highway reconstruction classes (ANOVA $F_{2,49} = 8.42$, $P = 0.005$)

[b] Passage rate for completed reconstruction section was less than the rate for control sections ($P = 0.037$) and sections under reconstruction ($P = 0.011$)

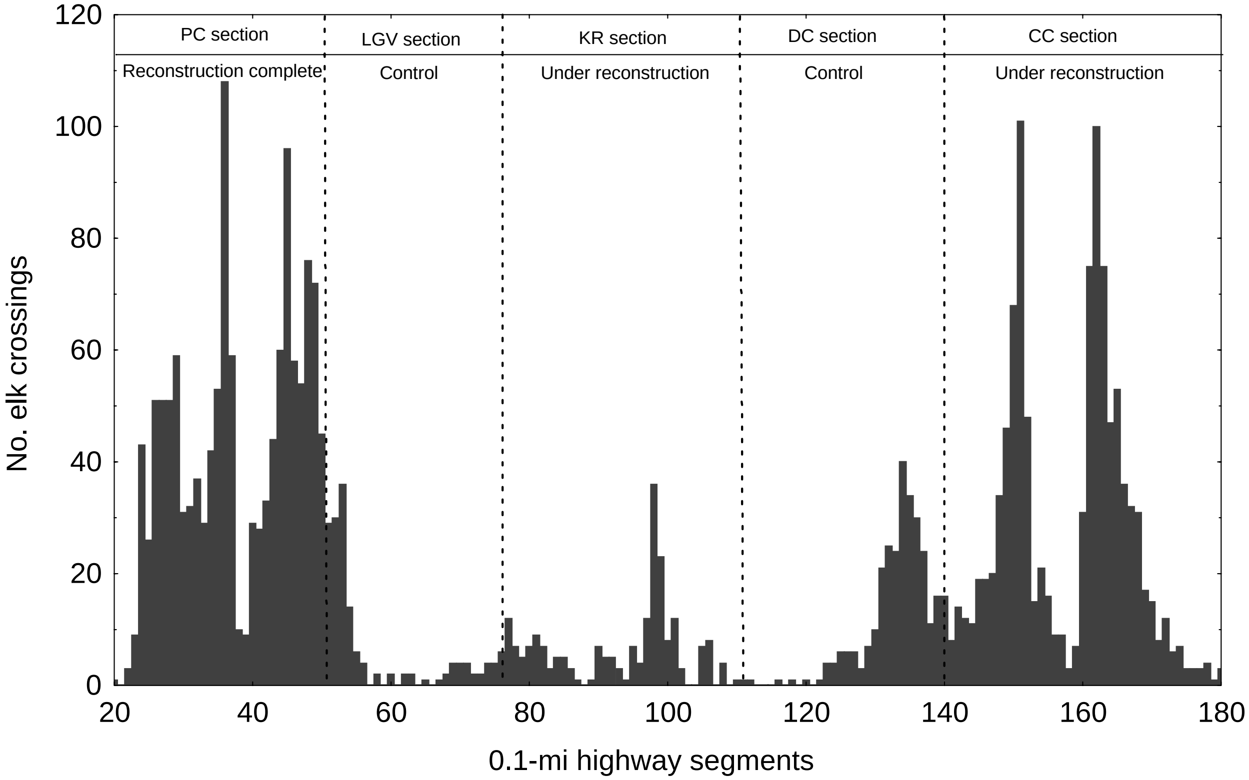

Figure 6.5. Frequency distribution of elk highway crossings by 0.1-mi segment, highway section, and reconstruction class along State Route 260, Arizona, determined from 33 elk fitted with Global Positioning System (GPS) receiver collars. We conducted GPS telemetry May 2002–April 2004.

6.4 DISCUSSION

Our application of GPS telemetry was central to the assessment of elk highway crossing patterns and passage along the SR 260 corridor. Few studies have calculated comparable highway passage or crossing rates (Forman et al. 2003). Only Paquet and Callaghan (1996) used passage rates as a measure of permeability, comparing approach and crossing rates for wolves along two highways by snow track counts; passage rates averaged 0.93 along a low-volume highway compared to 0.06 along the Trans-Canada Highway. Gibeau et al. (2001) used a relative crossing index to compare grizzly bear permeability along four highways and to investigate attributes associated with crossing zones. Both Waller and Servheen (2005) and McCoy (2005) compared bear highway crossing frequency from GPS telemetry to simulated random walk analyses to assess permeability. Observed grizzly bear crossing frequency was 31% of the simulated crossing frequency (Waller and Servheen 2005), and black bears not habituated to human food sources crossed the highway less than expected (McCoy 2005). Dyer et al. (2002) also compared actual road and simulated road network crossing rates; caribou crossed actual roads less than 20% as frequently as simulated networks.

In our study, both crossing and passage rates provided quantitative measures to compare permeability among SR 260 sections under different stages of highway reconstruction. Crossing rates as a measure of permeability, however, are potentially subject to bias associated with non-highway related factors that influence the proportion of time animals spend near the highway corridor, such as changes in habitat use over time (e.g., drought vs. non-drought conditions) or relative juxtaposition of sampled animals' home ranges in relation to the highway (Gagnon 2006). As a measure of permeability, passage rate is relatively free from such bias and provides a better means to experimentally assess highway effects associated with reconstruction or varying traffic volume (Gagnon 2006).

Rowland et al. (2000), Witmer and deCalesta (1985), and Rost and Bailey (1979) reported that elk selected areas away from roads and highways that for the most part had considerably less traffic volume than SR 260. Elk avoidance was particularly evident within 0.1 mi (Rost and Bailey 1979) to 0.15 mi (Witmer and deCalesta 1985) of roads, as was similar avoidance by other species including caribou (Dyer et al. 2001) and grizzly bear (Waller and Servheen 2005). In contrast, our elk distribution within 0.6 mi of SR 260 exceeded the expected (random) distribution. We hypothesize that elk attraction to riparian-meadow habitats accounted for their relative concentration adjacent to SR 260. Compared to the mean proportion of habitat within elk MCP home ranges, riparian-meadow habitat was nearly seven times more concentrated within the 0.6-mi zone around SR 260. Though constituting a minor proportion of all habitat types (0.04), a substantial proportion of GPS fixes occurred in riparian-meadow habitats, especially on a seasonal basis (e.g., in August 21% of all fixes and 46% of bull fixes occurred here; Dodd et al. 2006). Anderson et al. (2005) also found that elk selected areas near roads, attracted by high grass and forb biomass along the habitat edge associated with roads; they suggested that elk selected such areas to maximize quality forage intake.

Table 6.4. Mean proportions of vegetation types comprising minimum convex polygon (MCP home ranges, proportion of vegetation types within 0.6 mi of State Route 260, Arizona, mean proportion of elk Global Positioning System (GPS) fixes by vegetation type, and chi-squared (χ^2) comparison of observed versus expected proportions of each vegetation type used by 33 elk fitted with GPS collars. We conducted GPS telemetry May 2004–April 2004. We based our delineation of vegetation types on terrestrial ecosystem Geographic Information System analysis for the Tonto National Forest (S. Gorman, Tonto National Forest, unpublished data).

	Proportion of habitat area and elk GPS fixes by vegetative type				
Parameter	Chaparral	Pinyon-juniper	Ponderosa	Mixed conifer	Riparian
Proportion of habitat in home ranges (±SE)	0.05 0.01	0.37 0.05	0.31 0.03	0.26 0.03	<0.01 0.00
Proportion of habitat ≤0.6 mi from SR 260	0.16	0.12	0.46	0.22	0.04
Proportion of elk GPS fixes (±SE)	0.15 0.04	0.10 0.03	0.39 0.04	0.18 0.04	0.18 0.02
$\chi2$ observed versus expected (df = 31)	15.1 P = 0.992	9.3 P = 0.999	7.4 P = 0.999	7.8 P = 0.999	545.9 P < 0.001

Movement to and use of riparian-meadow habitats for foraging and watering, particularly during drought conditions appeared to be a key determinant of where elk crossed the highway (Section 10). Of six environmental factors modeled to discriminate between high versus low elk crossing sites along SR 260, Manzo (2006) found proximity to permanent water and meadows to be most influential. Riparian and meadow habitats provide forage of highest nutritional quality, earlier in the growing season than the forage growing on adjacent forest habitats (Nelson and Leege 1982), and best meet the high protein demands of cows during latter stages of gestation and the mineral demands of bull antler growth (Bubenik 1982, Nelson and Leege 1982). As with our study, of 10 available habitat types, elk in Alberta used only grass-meadow habitat more than expected, selecting for highest quality foraging areas (Jones and Hudson 2002). Riparian areas and drainages are also preferred travel lanes and corridors for elk (Skovlin 1982, Servheen et al. 2003). For these reasons, the SR 260 alignment adjacent to several stream courses and meadows has contributed to long-term wildlife-vehicle conflicts. Beside GPS crossing frequency, Dodd et al. (2006) found that frequency of elk-vehicle collisions by 0.1-mi segment was strongly associated with proximity to riparian-meadow habitat.

Despite the concentration of GPS fixes adjacent to SR 260, the lower frequency of observed versus random highway crossings nevertheless indicated decreased ability to cross the highway. The difference in passage rates among reconstruction classes illustrates the degree to which highway reconstruction has further reduced this ability. Yet the similar passage rates for controls and sections under reconstruction suggests that the lower ability to cross in the Preacher Canyon section was not solely a function of the increased footprint and direct habitat loss associated with highway reconstruction. In modeling highway-related wildlife avoidance behavior, Jaeger et al. (2005) differentiated between small and large roads with similar high traffic levels that elicit different levels of road surface avoidance by animals, with large roads having the greatest effects. Our passage rate differences are consistent with Jaeger et al. (2005) as the completed Preacher Canyon section is analogous to a large road whereas sections under reconstruction (including the Christopher Creek section, completed but without traffic on the new lanes) remained functional small roads. The relatively high passage rates associated with sections under reconstruction indicates that the presence of traffic on all lanes contributes more to the barrier effect than the physical footprint or size of the highway, also consistent with Jaeger et al. (2005).

Though passage rates differed among reconstruction classes, elk crossing rates did not. The attraction of elk to riparian-meadow habitat adjacent to SR 260 probably was sufficiently strong to cause elk to cross the highway at the same rate regardless of reconstruction class. Differences among passage rates indicate that elk attempting to cross the reconstructed Preacher Canyon section showed greater avoidance behavior (e.g., repels away from the highway) than other sections, as predicted by Jaeger et al. (2005). Thus, elk on the reconstructed section expended greater effort to achieve the same crossing rate as elk using other sections; crossing rate as measure of permeability was insensitive to such impact. Elk exhibit the potential for behavioral adaptation in crossing the highways, as noted by Servheen et al. (2003). In response to increasing traffic volume along SR 260, Gagnon (2006) found that elk crossed at lower volumes compared to when they initially approached the highway, crossed later in the night on higher-volume weekend days, and shifted distribution away from the highway with increasing traffic. For species more sensitive to highways such as grizzly bears (Waller and Servheen 2005) or wolves (Paquet and Callaghan 1996), a reduction in permeability similar to the magnitude we measured with highway reconstruction could constitute a significant barrier.

Along SR 260, most wildlife underpasses have been constructed near key riparian-meadow foraging areas. The attractive nature of riparian-meadow habitats should expedite acceptance and use of underpasses by elk (Clevenger and Waltho 2003), especially where fencing is erected to limit at-grade crossings and funnel animals to underpasses (Clevenger et al. 2001). For instance, on the Preacher Canyon section, 34% of elk crossings recorded by the GPS receivers were along the limited 0.4-mi stretch (13% of the section) fenced in conjunction with two underpasses. The mean frequency of elk crossings/segment (80.2) associated with this stretch was one of the highest among all highway sections. Thus, fencing itself does not appear to limit elk permeability above that caused by highway reconstruction where underpasses are situated in proximity to existing or traditional travel corridors and natural habitats (Foster and Humphrey 1995, Bruinderink and Hazebroek 1996, Ng at al. 2004). The overall distribution of underpasses and bridges within our study area (1 passage structure/1.0 mi) and associated fencing should limit wildlife at-grade crossings and funnel animals to underpasses without creating a continuous barrier limiting highway permeability.

In addition to providing a quantitative measure of highway permeability, elk crossing data supported our ongoing efforts to reduce wildlife-vehicle collisions through adaptive management during highway reconstruction . We used these data to project proportions of elk crossings that would be intercepted under various fencing scenarios. We identified where fencing an additional 26% of the Christopher Creek section (to 49% total) was projected to intercept an additional 45% of elk crossings determined by GPS telemetry (58% total), serving to reduce at-grade elk crossings and collisions, while maintaining permeability via seven passage structures (Figure 6.6). In the year after all fencing was erected (2004), elk-vehicle collisions were reduced by more than 80% over the previous year (Dodd et al. 2006; Dodd et al. 2007*c*, Section 7). Along the Kohl's Ranch Section, completed in March 2006, a similar approach was taken whereby the planned extent of fencing was projected to intercept only 8% of elk crossings. We recommended increasing the extent of fencing to only ⅓ of the section, but this was projected to intercept 70% of elk crossings. While limited fencing of the Preacher Canyon section did promote use of the two underpasses (with 26% crossing interception) the post-construction elk-vehicle collision rate did not change from pre-construction levels (Dodd et al. 2006). Based on our GPS data that reflected a sheet crossing pattern when compared to other sections, the entire Preacher Canyon section was fenced in late 2006 to reduce elk-vehicle collisions, and is projected to intercept more than 95% of elk crossings. Since 2005, we have been employing GPS telemetry to assess the degree to which highway permeability is affected by fencing on the Preacher Canyon section.

Our study demonstrated that GPS telemetry provides an effective means of assessing highway permeability to large, mobile wildlife, particularly under experimental approaches comparing permeability before and after highway reconstruction and erection of ungulate-proof fencing. Our application of GPS telemetry allowed us to quantify indirect highway impacts to elk from diminished highway permeability associated with highway reconstruction. Reductions in permeability of the magnitude we documented may constitute a significant barrier to highway crossings for many species, especially those most sensitive to highways. Data from our GPS telemetry also supported efforts to mitigate highway impacts to elk by developing fencing strategies to maximize the effectiveness of passage structures, promote permeability, and reduce wildlife-vehicle collisions.

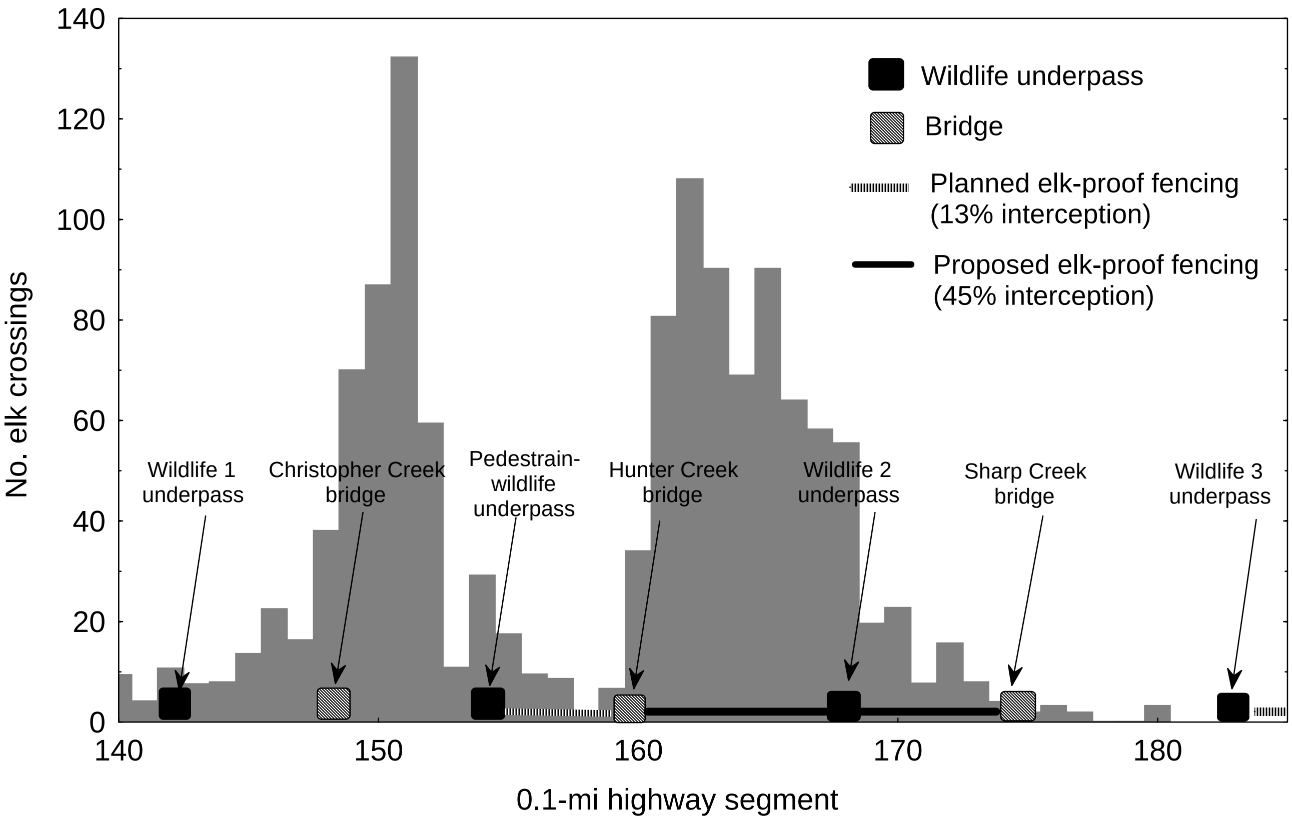

Figure 6.6. Frequency distribution of elk highway crossings by 0.1-mi segment for Christopher Creek section, State Route 260, Arizona, and projected proportions of total crossings intercepted with planned and proposed elk-proof fence. We determined crossing frequency from 14 elk fitted with Global Positioning System (GPS) receiver collars May 2002–April 2004.

7.0 ROLE OF FENCING IN PROMOTING WILDLIFE UNDERPASS USE AND HIGHWAY PERMEABILITY[5]

7.1 INTRODUCTION

As our understanding of highways' impact on wildlife has increased in the past decade, so have comprehensive efforts to mitigate these impacts when planning highway construction and maintenance projects. Structures designed to promote wildlife passage across highways are increasingly being built 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, Section 4 and Dodd et al. 2007*a*). Transportation agencies are increasingly receptive to integrating passage structures in highway projects to address both safety and ecological needs (Farrell et al. 2002) with the expectation that they will yield desired benefits (Clevenger and Waltho 2000).

Ungulate-proof fencing ranging in height from 6.5–8 ft has been shown to be effective in reducing wildlife-vehicle collisions, especially when used in conjunction with passage structures (Romin and Bissonette 1996*a*, Forman et al. 2003). Ward (1982) reported more than 90% reduction in collisions with mule deer where underpasses and fencing were applied in Wyoming, though modifications to the original fencing were needed to achieve this reduction. Woods (1990) reported 94-97% reductions in collisions 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 collisions with moose (*Alces alces*) in Sweden were attained with fencing (Lavsund and Sandegren 1991).

Though fencing is generally regarded as effective in reducing wildlife-vehicle collisions, mixed results nonetheless have been reported (Falk et al. 1978), especially where animals cross at the ends of fencing, resulting in zones of increased collisions (Feldhamer 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 fence extensive stretches of highways. And while fencing is often regarded as an integral component of effective passage structures (Romin and Bissonette 1996*a*, Forman et al. 2003), limited information or guidelines exist for the application of fencing in conjunction with wildlife passages. As fences themselves constitute effective barriers to ungulate passage across highways (Falk et al. 1978), fencing may exacerbate the reduction in wildlife permeability (ability to cross barriers) associated with highways alone (Dodd et al. 2007*b* and Section 6), particularly where effective measures to accommodate animal passage are lacking.

ADOT's general model for integrating 8-ft ungulate-proof fencing with underpasses has been to erect limited (less than 300 ft) wing fences outward from each underpass and most bridge abutments to funnel animals toward the structures. The agency has

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[5] An early version of this chapter was published in the Proceedings of the 2007 International Conference on Ecology and Transportation (see Dodd et al. 2007*c*)

embraced an adaptive management approach to reconstruction where our have been used to make modifications to underpass design (Section 4 and Dodd et al. 2007*a*) and the strategic placement of fencing to intercept crossing wildlife as determined from Global Positioning System (GPS) telemetry (Dodd et al. 2007*b* and Section 6).

On one 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 underpasses, as well as wildlife-vehicle collision patterns before and after fencing was erected. The majority of underpass 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 in Section 4 and by Dodd et al. (2007*a*) and Clevenger and Waltho (2003).

During the period that this section was under reconstruction, we analyzed Rocky Mountain elk movement and crossing patterns and passage across the highway corridor (Dodd et al. 2007*b* and Section 6). We found that the elk passage rate on the lone completed section opened to traffic was lower than the mean rate for the two control sections and the two sections under reconstruction, including the section under study here. This gave us the opportunity to compare permeability before (Section 6 and Dodd et al. 2007*b*) 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 the underpasses. Numerous studies have alluded to highway barrier effects on wildlife (e.g., see Forman et al. 2003, Section 6 and Dodd et al. 2007*b*), 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 assess and compare:

- elk highway crossing patterns and permeability before and after the highway was opened to traffic but before fencing was erected,
- elk highway crossing patterns and permeability before and after fencing was erected after the highway was opened to traffic,
- wildlife use of underpasses before and after fencing was erected, focusing on elk, mule deer and white-tailed deer, and
- wildlife-vehicle collision patterns before and after fencing was erected.

We attempted to determine the influence of fencing on wildlife use of underpasses and to develop recommendations on the use of fencing in conjunction with wildlife underpasses to maximize their effectiveness in reducing collisions and maintaining wildlife permeability.

7.2 STUDY AREA

We conducted this aspect of our study along the 5-mi Christopher Creek section of SR 260. Reconstruction of this section, the second of five phased reconstruction sections, was initiated in early-2002. Four large bridged underpasses designed specifically for wildlife passage along with two large bridges over streams and an access road underpass were constructed in this section (Table 7.1, Figure 7.1); on average, a passage structure was constructed every 0.7 mi along the section.

Table 7.1. Physical characteristics associated with wildlife underpasses (UP) and bridges on the Christopher Creek section of State Route 260, Arizona, and whether video surveillance of wildlife use was conducted at the passage structure.

Passage structure	Span (ft)	Height (ft)	Width (ft)[a]	Length (ft)[b]	Atrium (ft)[c]	Video system
Wildlife 1 UP	330	50	105	360	80	No
Christopher Creek bridge	520	58	250	300	65	No
Pedestrian/wildlife UP	110	22	30	420	155	Yes
Hunter Creek access UP	125	21	75	370	175	No
Wildlife 2 UP	130	32	30	390	105	Yes
Sharp Creek bridge						
Eastbound lanes	570	57	265			No
Westbound lanes	130	21	65	575	410	Yes
Wildlife 3 UP	125	17	32	210	None	Yes

[a] Width = distance at the floor excluding fill slopes

[b] Length = distance for animals to fully negotiate passage structure, from mouth to mouth including fill material

[c] Atrium = width of opening between eastbound and westbound bridge spans

The majority of heavy reconstruction on the Christopher Creek section, including bridge and underpass construction was completed by May 2003, at which time wildlife could pass through the unfenced underpasses and bridges. 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 8-ft metal pipe, T-post, and mesh wire ungulate-proof fencing adjacent to 0.7 mi of the section (22%). This extent of fencing was increased to 2.4 mi (49%; Figure 7.1) by raising the existing 3.5-ft right-of-way fence to 7.5 ft 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. 2007*b* and Section 6). During the extension of the ROW fence a 0.2-mi gap was left in the fence midway along a 2.0-mi stretch of fenced highway due to complexities associated with integrating fencing at a lateral access road into the community of Christopher Creek (Figure 7.1). 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 (Figure 7.2) adjacent to 0.5 mi of the highway was evaluated as an alternative treatment to deter at-grade wildlife crossings. This treatment was projected to intercept 27% of the GPS-identified elk crossings (Dodd et al. 2007*b* and Section 6).

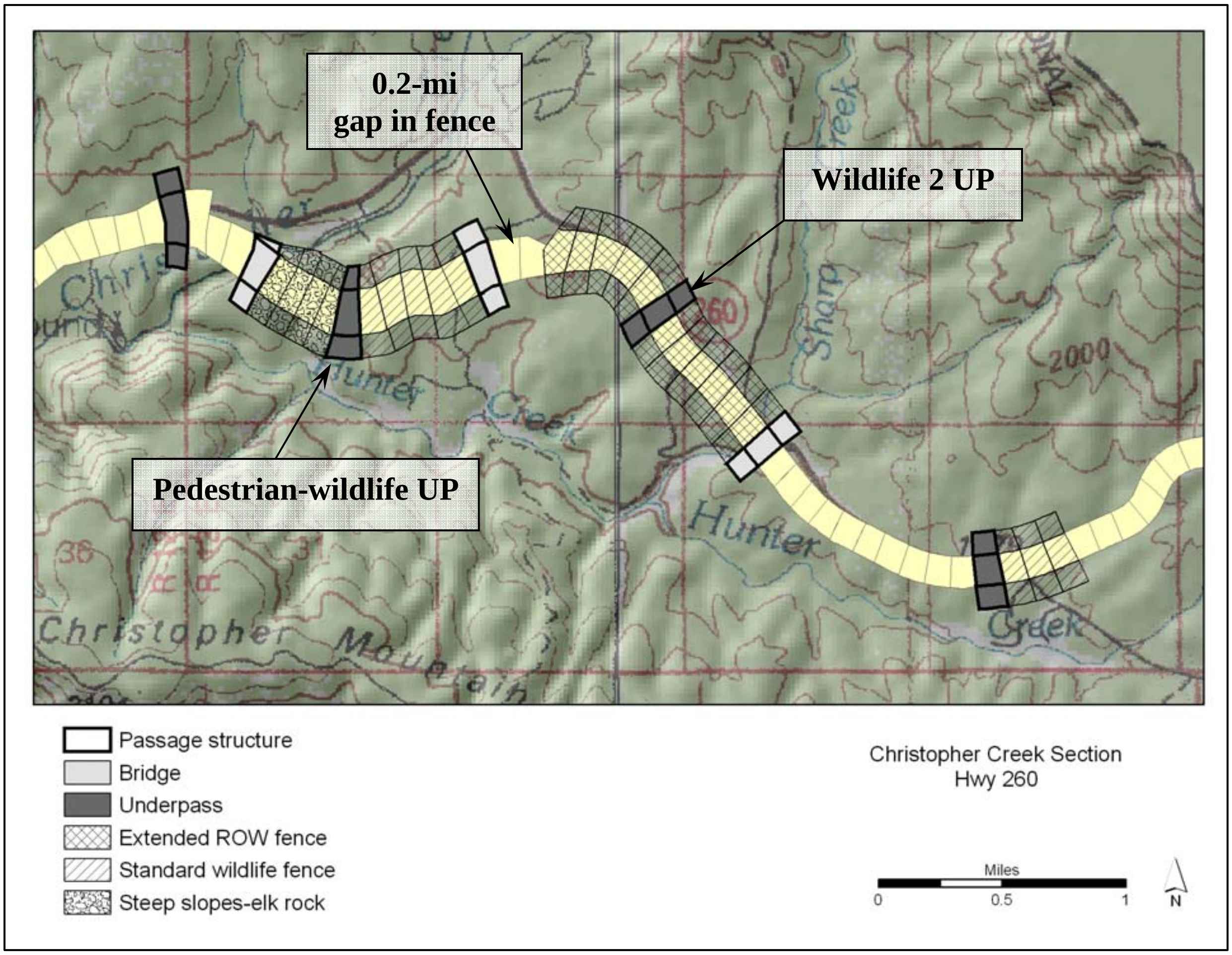

Figure 7.1. Location of wildlife underpasses and bridges along the Christopher Creek section of State Route 260, Arizona, and delineation of different treatments to deter wildlife passage onto the highway and funnel animals toward passage structures. Also identified are the 0.2-mi gap in the fence at the east entrance into Christopher Creek and the 2 underpasses where video surveillance was conducted.

7.3 METHODS

We used data on elk crossing patterns and passage rates and wildlife-vehicle collision patterns that was collected when the Christopher Creek section was under reconstruction (Dodd et al. 2006, Dodd et al. 2007*b* and Section 6). We used these baseline data to make comparisons among the following three highway reconstruction classes: 1) under reconstruction, 2) post reconstruction-before fencing (henceforth "before fencing"), and 3) post reconstruction-after fencing (henceforth "after fencing"). The availability of during-reconstruction data allowed us to make comparisons of our elk permeability and wildlife-vehicle collision patterns data among all three treatment classes. Our comparisons of underpass wildlife use however were limited to before- and after-fencing, as the video camera surveillance systems employed to assess wildlife use were not installed until after reconstruction was completed. Statistical tests for GPS telemetry and wildlife-vehicle collision data were performed using the program STATISTICA® (Statsoft, Inc. 1994) while wildlife underpass use was analyzed with program JMP 5.1 (SAS Institute 2005). Results were considered significant at $P \leq 0.05$. Mean values were reported with ± one SE.

Figure 7.2. Alternatives to fencing to deter at-grade wildlife crossings along the Christopher Creek section of State Route 260, Arizona. 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.

7.3.1 Comparison of elk crossing patterns and permeability

We captured elk at six trap sites spaced an average of 0.7 mi apart along the Christopher Creek section and at one site each on the Kohl's Ranch and Doubtful Canyon sections, similar to what was described in Section 6 and 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 1000 ft 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 made by Telonics, Inc. of Mesa, Arizona, which were programmed to receive a fix every 1.5 hours from 5:00p.m. –9:00 a.m. (12 fixes) and one at 12:00 noon; operational battery life was 22 months.

We used ESRI's ArcGIS® Version 8.3 and ArcView Version 3.1 software and Animal Movement ArcView Extension Version 1.1 software (Hooge and Eichenlaub 1997) to analyze GPS data similar to Section 6 and Dodd et al. (2007*b*). We divided the length of the Christopher Creek section into 50 sequentially numbered 0.1-mi segments (Figure 6.2) 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 (Figure 6.2). We compiled individual elk crossings by highway segment and calculated crossing rates for individual elk by dividing the number of crossings by the number of days a collar was worn.

We calculated elk passage rates as per Section 6 and Dodd et al. (2007*b*); passage rates were considered our best relative measure of highway permeability (e.g., compared to crossing rates; Section 6 and Dodd et al. 2007*b*). An approach was counted when an elk traveled to within 0.15 mi of the highway, as determined by successive GPS fixes (Figure 6.2); successive fixes within 0.15 mi of the highway were treated as a single approach. 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 in Section 6 and Dodd et al. (2007*b*) when the Christopher Creek 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 Analysis of Variance (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, Section 6 and Dodd et al 2007*b*). 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 Christopher Creek section for three crossing-deterrent treatments: 1) fenced, 2) steep slopes-elk rock, and 3) not fenced (Figure 7.1). 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, we made post hoc pairwise comparisons with a Tukey test for unequal sample sizes.

7.3.2 Comparison of elk-vehicle collision patterns

To document wildlife-vehicle collisions 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 ADOT's Data Management Section (ADOT, unpublished data), which includes data on wildlife-vehicle collisions. Records in this database included the date, time, and location of the collision, and wildlife species involved (genus only in the case of deer). 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 wildlife-vehicle collision tracking form for use by agencies' and research project personnel to document all wildlife-vehicle collisions, including roadkills. This database reflected concerted efforts to regularly search for and document wildlife-vehicle collisions, especially by research project personnel Our database included the same information as the ADOT database, including species of deer. All wildlife-vehicle collisions were recorded to the nearest 0.1 mi

We compared only collisions involving elk among the reconstruction classes 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. Elk underpass use (Dodd et al. 2007*a)* and highway crossing patterns (Gagnon 2006), varied by season, 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 ANOVA, post hoc pairwise comparisons were accomplished using a Tukey test for unequal sample sizes.

7.3.3 Wildlife Underpass Use Comparison

We used triggered four-camera video surveillance systems (Figure 4.2) described in Dodd et al. (2006) and Gagnon et al. (2006) to examine the number of elk and deer that used the underpasses on the Christopher Creek section. These systems included two cameras that recorded animals approaching the underpasses from one side (approximately 130–150 ft from the underpasses' mouth) and the other two cameras recording animals as they passed through. Though video camera systems were installed at four underpasses on the Christopher Creek Section (Table 7.1), only two systems were installed prior to fencing, limiting our before- and after-fencing comparison of underpass wildlife use to the Pedestrian/Wildlife and Wildlife 2 underpasses (Table 7.1, Figure 7.1) located 1.5 mi apart. Both had separate east- and west-bound bridges with open atria between bridges (105–150 ft; Table 7.1).

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

We considered an approach to occur when animals crossed over the 3.5-ft ROW fence approximately 130–150 ft from the mouth of the underpass. 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 underpass and assigned them to two approach categories based on their subsequent behavior as recorded by our cameras:

- *Attempted to cross* – animals that approached the highway corridor in the vicinity of the underpass and attempted to cross the highway either via the underpass or over the highway.

- *No attempt to cross* – animals that were at the underpass but appeared to have had no intention of crossing the highway.

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

- *Avoid underpass 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 2 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 use of the underpasses did not differ before and after fencing. To test the hypothesis that probability of use was independent of fencing we compared the number of observed successful elk and deer crossings to expected crossings 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 of an elk or deer using the underpasses, both combined and individually with and without fencing using 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 underpasses 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 underpass use by wildlife.

7.4 RESULTS

7.4.1 Comparison of elk crossing patterns and permeability

We fitted 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 Christopher Creek 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 acquired 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 0.6 mi of SR 260. On average, we obtained 5.1 fixes/day/elk (±0.5) from within 0.6 mi of the highway. Elk came within 0.15 mi of the highway (approach distance) on 12,563 occasions with a mean of 571.0 fixes/elk (±107.3).

Our collared elk crossed the Christopher Creek section 2,692 times, with a mean of 122.4 crossings/elk (±25.3) that ranged from 14–402 crossings; 986 crossings occurred before fencing was erected and 1,706 crossings after. The number of different elk crossing at each 0.1-mi 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. 2007*b*; Table 7.2). Post reconstruction, our elk crossed the highway an average of 0.38 times/day before and 0.35 times/day after fencing was erected (Table 7.2). Among the three treatments, there was no difference in highway crossing rates (ANOVA $P = 0.618$; Table 7.2).

Compared to our mean elk passage rate of 0.79 while the Christopher Creek section was under reconstruction (Dodd et al. 2006b; Table 7.2), permeability was 31.6% lower, or 0.54 following reconstruction but before fencing was erected (Table 7.2). Once fencing was erected, the passage rate rebounded 51.8% to 0.82 crossings/approach (Table 7.2). 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 7.2).

We found differences among the three passage-deterrent treatments in the proportion of elk crossings before and after fencing along highway stretches between passage structures (ANOVA $F_{2,5} = 7.27$, $P = 0.033$; Table 7.3). 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 7.3). On unfenced stretches the mean proportion of elk crossings increased 39.7% from 0.07 to 0.10 (mean change = 0.03; Table 7.3) once fencing was erected; the proportion of crossings increased 106.2%, from 0.03 to 0.07 at the 0.2-mi gap in the fence at the Christopher Creek 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 7.3).

Table 7.2. 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. GPS telemetry conducted 2002–2004 for during reconstruction (Dodd et al. 2007*b* and Section 6) and 2004–2006 for the post-construction treatments. Letters denote significant differences for Tukey test pairwise construction class comparisons for significant ANOVA among classes.

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

[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

7.4.2 Comparison of elk-vehicle collision patterns

From 2002–2006, we documented 139 wildlife-vehicle collisions along the Christopher Creek section, 110 with elk (79.1%) and 29 with deer (20.9%). Nineteen elk-vehicle collisions were recorded in both 2002 and 2003. The number increased 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 (Figure 7.3). Elk-vehicle collisions dropped to 12 in 2005 (Figure 24) 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.

Table 7.3. Mean proportion of elk highway crossings along the Christopher Creek section, State Route 260, 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*)	Mean proportion of elk crossings		Mean Δ in proportion of elk crossings[a]	(±SE)
	Before fencing	After fencing		
Ungulate-proof fencing ($n = 3$)	0.20	0.10	-0.10 A	(0.02)
Steep slopes- "elk rock" ($n = 1$)	0.12	0.19	+0.07 B	-
None ($n = 4$)	0.07	0.10	+0.03 A,B	(0.02)

[a] Mean Δ in proportion of crossings differed among passage deterrent classes (ANOVA $F_{2,5} = 7.27$, $P = 0.033$)

We found seasonal differences in elk-vehicle collisions among the treatments ($F_{2,17} = 31.4$, $P < 0.001$; Table 7.4). 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 7.4). Of the elk-vehicle collisions that occurred in 2005 (12) and 2006 (8) since the Christopher Creek 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 Christopher Creek access road.

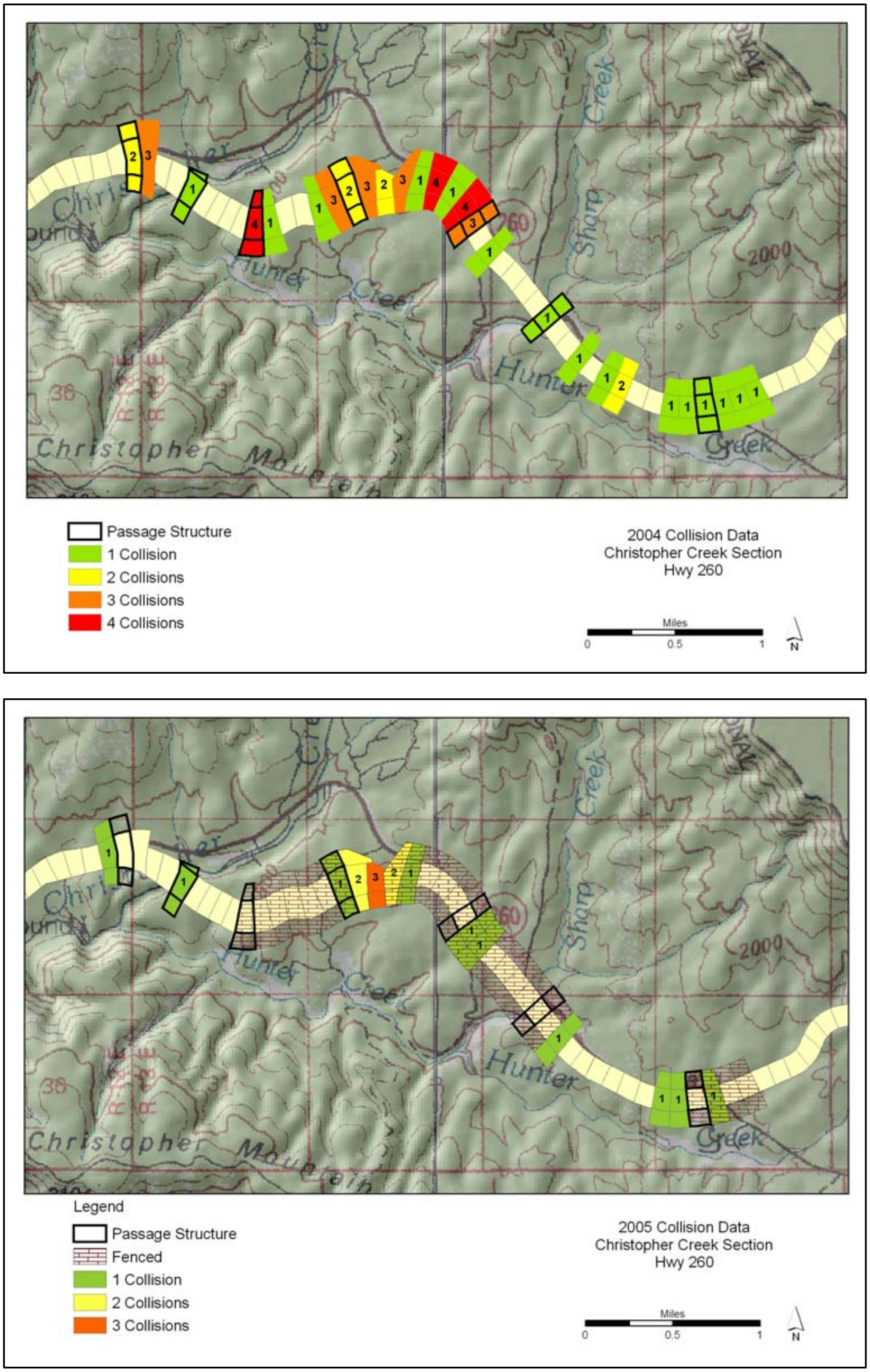

Figure 7.3. Number of elk-vehicle collisions recorded along the Christopher Creek section of State Route 260, Arizona, in 2004 (top; total 51 collisions) before ungulate-proof fencing was erected and 2005 (bottom; 12 collisions) after fencing was erected. Note the concentration of collisions in 2005 at the 0.2-mi gap in the fence near the entrance to Christopher Creek.

7.4.3 Wildlife Underpass Use Comparison

We recorded 500 elk and deer that approached the two underpasses from their camera side 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 underpasses altogether and crossed at grade both sets of highway lanes in the vicinity of the underpasses. Another 74 elk and deer (0.21) were recorded crossing under the first bridge then moving into the median and crossing the other set of lanes at-grade . Overall, only 12% of the elk and deer used the underpasses to entirely cross below grade prior to fencing. During the 11-month period after fencing, we recorded 595 elk and deer that we determined were approaching the two underpasses, of which 331 used them to successfully cross (55.6%). We did not document any highway crossings at grade in the vicinity of the underpasses after fencing was erected.

The mean frequency of daily successful underpass crossings by deer and elk increased 345.4% between the equivalent 9-month periods before ($\bar{x}$ = 0.66 ±0.61 SD) and after ($\bar{x}$ = 2.94 ±0.66 SD) fencing was erected on the Christopher Creek Section (Mann-Whitney U-Test U_s = 12.8, df =1, $P < 0.001$). Mean monthly successful elk and deer underpass crossings increased over six fold between the nine-month period before ($\bar{x}$ = 11.5 ±SD 9) and after ($\bar{x}$ = 65.4 ±SD 13) fencing was erected (U_s = 12.8, df =1, $P < 0.001$).

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

7.5 DISCUSSION

We documented a benefit from ungulate-proof in reducing wildlife-vehicle collisions 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, which maximizes 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 underpasses and bridges along SR 260, heretofore undocumented by previous studies.

Prior GPS telemetry by Dodd et al. (2007*b*, Section 6) provided an unprecedented opportunity to assess the degree to which highway reconstruction impacts wildlife permeability. The diminished passage rate reported for the Christopher Creek 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. (2007*b* and Section 6). We 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. (2007*b*; Section 6) did not compare passage rates along the same section of highway in an experimental context as we did in this study. Dodd et al. (2007*b*; Section 6) 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).

Table 7.4. Mean collisions/season (2002–2006) by season and highway reconstruction class along the Christopher Creek section, State Route 260, Arizona. Letters denote significant differences for Tukey test pairwise construction class comparisons for significant ANOVA among classes.

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

[a] Collisions differed among highway reconstruction classes (ANOVA $F_{2,17} = 31.4$, $P < 0.001$)
[b] Collisions for post reconstruction - before fencing class was higher than the rate for during reconstruction ($P < 0.001$) and post reconstruction - after fencing ($P < 0.001$) classes

Numerous studies have alluded to the benefit of passage structures in maintaining or enhancing habitat continuity 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 increased underpass use by wildlife but in promoting permeability; in our case, both components were integral to mitigating the impact of highway reconstruction and reducing wildlife-vehicle collisions. We attribute the recovery in the elk passage rate to before-reconstruction levels following fencing to the funneling of animals toward underpasses and bridges where they were presented below-grade opportunities for crossing that apparently ameliorated the road avoidance and resistance to crossing of a large roadway at grade (Jaeger et al. 2005) and traffic-associated impact reported by Gagnon (2006). Though Gagnon (2006) and Gagnon et al. (2007*b* and Section 8) 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 the five wildlife underpasses along SR 260 (Gagnon 2006, Gagnon et al. 2007a and Section 5), as illustrated in Figure 7.4 from (Gagnon et al. 2007*c*).

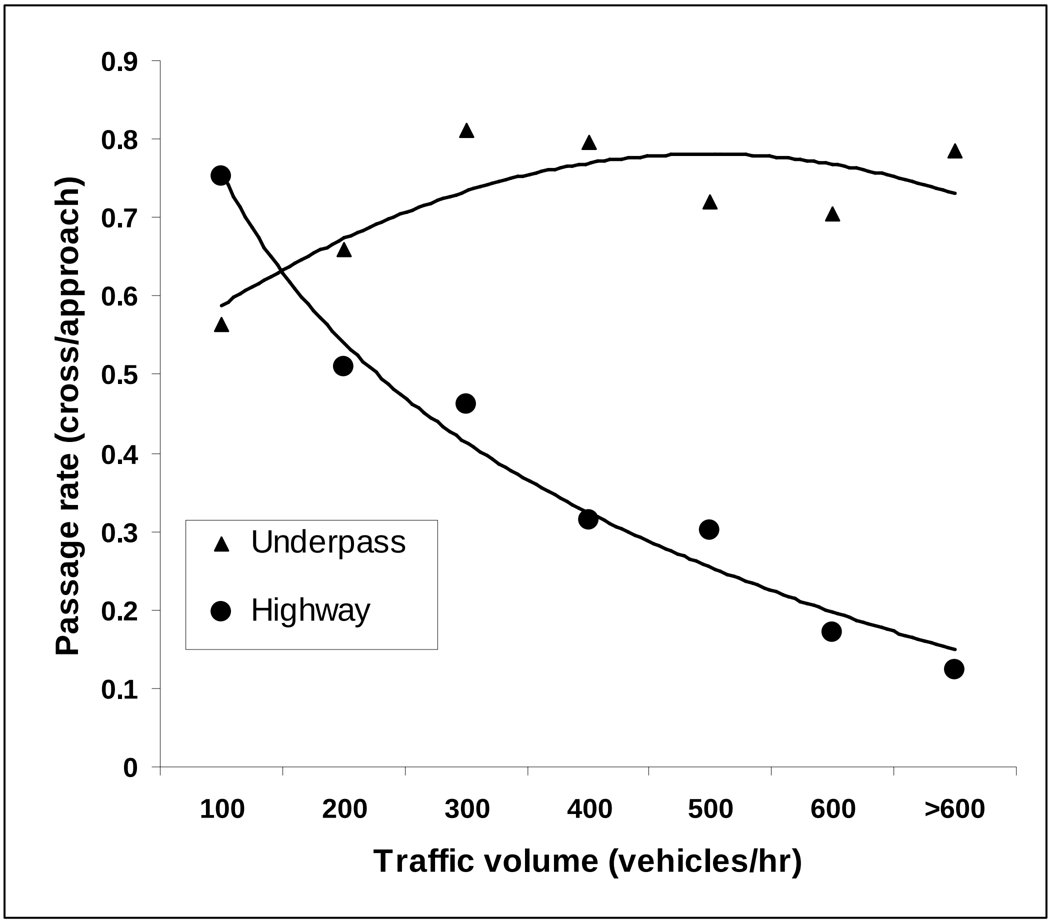

Figure 7.4. At-grade and below-grade (through 6 wildlife underpasses) elk passage rates at varying traffic volume levels along State Route 260, Arizona, (figure from Gagnon et al. 2007*c*). At-grade passage rates determined from GPS telemetry tracking of 44 elk from 2003−2006 (Section 8 and Gagnon et al. 2007*b*) and below-grade underpass passage rates determined from video surveillance of wildlife use of underpasses from 2002−2006 (Section 5 and Gagnon et al. 2007*a*).

We suspect that the success in promoting elk permeability with underpasses and fencing is partly attributable to the relatively high density of suitable passage structures along the Christopher Creek section, though the degree to which spacing of structures contributed to permeability is uncertain. Bissonette (2006) applied allometric scaling principles to theorize on the ideal spacing of 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 2.2 mi. On the Christopher Creek section, our passage structures were spaced considerably closer with an average of 0.7 mi between them. Elsewhere on SR 260, ungulate-proof fencing was erected in late 2006 along three mi of the Preacher Canyon section. Here the average passage structure spacing is 1.5 mi, intermediate between that recommended by Bissonette (2006) and the spacing associated with our study. Permeability on the unfenced Preacher Canyon section averaged 0.43 crossings/approach (Dodd et al. 2007*b* and Section 6), and after 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 different elk passage rates for the Pedestrian/Wildlife (59%) and Wildlife 2 (27%) underpasses on the Christopher Creek section, and hypothesized that the differential use was at least partly attributable to the degree of offset of bridges at each underpass. At the Pedestrian/Wildlife underpass, the two bridges were constructed in line such that wildlife can see through the entire underpass from any approaching angle. The Wildlife 2 underpass was constructed with an offset along an existing drainage that ran diagonally to the highway, severely limiting visibility through it. With the erection of fencing, we noted a substantially greater benefit (e.g., more than 2.5 times higher odds of successful crossings after fencing) achieved in "forcing" animals to use the Wildlife 2 versus the Pedestrian/Wildlife underpass. 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 near preferred foraging areas or established travel corridors (Beier and Loe 1992, Bruinderink and Hazebroek 1996, Dodd et al 2007*a* and Section 4). Though animals continually habituated to underpasses during the course of our study, we do not believe that this accounted for the dramatic increase in wildlife use of the two underpasses before and after fencing. As our underpasses 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 to the underpasses had occurred in advance of our study, especially by elk which readily adapt to new underpasses (Clevenger and Waltho 2003, Dodd et al. 2007*a* and Section 4).

Strategic fencing of peak elk crossing areas as determined through GPS telemetry (Dodd 2007*b* and Section 6), which accounted for only 49% of the Christopher Creek 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-mi gap at the entrance to Christopher Creek is fenced to eliminate elk crossings that account for half the collisions along the Christopher Creek 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.

8.0 INFLUENCE OF FLUCTUATING TRAFFIC VOLUME ON ELK DISTRIBUTION AND HIGHWAY CROSSINGS[6]

8.1 INTRODUCTION

As highways are upgraded and expanded, their negative effects on wildlife also increase. Four primary negative effects of roads on wildlife are: increased mortality due to collisions, increased population fragmentation, altered habitat use, and direct habitat loss (Noss and Cooperrider 1994, Forman et al. 2003, Ruediger et al. 2006). The magnitude of these effects may depend on the volume of traffic on a highway or type of highway (Brody and Pelton 1989, Forman et al. 2003, Jaeger et al. 2005), but few studies have documented how wildlife respond to fluctuating traffic volumes (Wisdom et al. 2005).

Vehicular collisions with large ungulates are costly and result in human injuries, fatalities (Conover et al. 1995) and wildlife mortality. it is estimated that in the United States alone, 700,000 to more than 1 million deer-vehicle collisions occur annually (Schwabe and Schuhmann 2002, Conover et al. 1995), with associated costs that exceed $1 billion to $2 billion (Conover et al. 1995, Danielson and Hubbard 1999). In Europe, an estimated 300 people are killed and 30,000 injured in over 500,000 ungulate-vehicle collisions annually (Groot Bruinderink and Hazebroek 1996). Although researchers disagree about whether increasing traffic volume is the primary reason for increasing ungulate-vehicle collisions (McCaffery 1973; Reilly and Green 1974; Allen and McCullough 1976; Case 1978; Romin and Bissonette 1996), many recognize traffic volume is an important factor, along with other factors such as wildlife population fluctuations, wildlife behavior, driver behavior, and temporal and spatial environmental factors (Carbaugh et al. 1975, Bashore et al. 1985, Groot Bruinderink and Hazebroek 1996, Haikonen and Summala 2001, Seiler 2004, Gunson and Clevenger 2003, Manzo 2006).

Traffic may serve as a “moving fence” that can render highways impermeable to wildlife (Bellis and Graves 1978). One theoretical model (Iuell et al. 2003) predicts that a highway could become an impermeable barrier to most wildlife at 10,000 vehicles/day, potentially leading to fragmentation and rapid genetic differentiation of wildlife subpopulations like that documented for bighorn sheep (Epps et al. 2005). Alternatively, because traffic volume varies seasonally, weekly and by time of day, some animals may be able to cross even high traffic volume highways when traffic volume is relatively low.

Previous studies of the effects of roads on elk focused on habitat selection by examining pellet count densities (Perry and Overly 1976; Rost and Bailey 1979; Lyon 1979), or radio-telemetry relocations at varying distances from roads (Witmer and deCelesta 1985). These studies suggested that habitat effectiveness was reduced as road density or road types associated with different traffic volumes (e.g., secondary, primary roads) increased.

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[6] An early version of this chapter was published in the *Journal of Wildlife Management* (see Gagnon et al. 2007*b*)

In these cases, traffic volume was associated with different road types, confounding the effect of traffic with potential differences in habitat, resource availability, and human disturbance. More recent studies (Rowland et al. 2000; Wisdom et al. 2005), have confirmed this pattern, but in these studies traffic volumes were relatively low (unpaved forest or low-use paved roads) and therefore little was determined about how fluctuating traffic volume affects elk distributions and movements along high-traffic highways (Ruediger et al. 2006).

In this study, we examined the effects of fluctuating hourly traffic rates on the distribution and movements of Rocky Mountain elk along SR 260, a relatively high-traffic-volume highway. We explored: 1) how elk distribution relative to the highway varied at differing traffic volumes, and 2) how traffic volume interacted with other potentially important factors to determine the probability of elk crossing the highway.

8.2 METHODS

We estimated traffic volume using a permanent traffic counter programmed to record mean hourly traffic volumes. In cooperation with ADOT, we installed the traffic counter in December 2003 at the center of our study area, on the Little Green Valley section (Figure 8.1). No major roads branched off the highway along the length we studied and vehicles could move from either end of the study area to the traffic counter in no more than 10 minutes. We assumed that traffic volume recorded by the counter accurately represented levels present along that stretch of highway during any one hour interval.

We obtained Global Positioning System (GPS) relocations from 2001 through 2006 from 44 elk (7 bulls, 37 cows) fitted with TGW-3600 store-on-board radio collars manufactured by Telonics, Inc. of Mesa, Arizona (Dodd et al. 2007*a*). All collars were recovered by June 2006, providing approximately 30 months of data concurrent with the operation of our traffic counter. GPS fixes were accrued at 2-hour intervals, and were accurate to ±32.8 ft (Dodd et al. 2007*b* and Section 6). We only used fixes recorded between 5:00 p.m. and 8:00 a.m. because this was when elk were most active and less than 3% of crossings occurred outside of this period. We combined traffic and GPS data by assigning traffic volumes for the previous hour to each GPS location using ESRI's ArcGIS® Version 9.1. This allowed us to correlate the traffic volume each elk encountered along the highway in the hour prior to movement to a particular point, regardless of distance traveled.

We examined how the proportion of elk relocations at different distances from the highway varied with traffic volume by calculating the percentage of relocations in each 330-ft distance band, out to a maximum of 2,000 ft (similar to Rowland et al. 2005). We considered elk within 2,000 ft of the highway potentially capable of crossing the highway, because the upper end of the 99% CI for distance between 2-hour intervals for elk that crossed the highway during this study was under 2,000 ft. To avoid bias due to differences in the number of relocations for individual elk, we used the proportion of relocations occurring in each distance band for each elk as the sample unit, rather than total relocations. We then calculated a mean proportion across all 44 elk within each 330 ft-distance band at varying traffic volumes.

To investigate how traffic volume influenced the probability of elk crossing the highway, we used a multiple logistic regression approach (Agresti 1996) and assigned a binomial response to two different behaviors: 1) movement near the highway in which crossing was not detected, and 2) movement that resulted in a crossing. We defined a non-crossing movement as an instance when two successive GPS relocations indicated elk entered the 0.15 mi zone adjacent to the highway from beyond that distance, but did not cross the highway. The 0.15 mi zone was chosen based on the mean movement of elk during crossings. Because the upper limit of the 99% CI for highway crossings by all elk during this study was under 2,000 ft, we assumed fewer than 1% of elk could enter this 2,000 ft zone (820 on each side of the 330-ft highway "footprint") from either direction and cross the highway without being detected.

Figure 8.1. Permanent traffic counting station installed along the Little Green Valley section of State Route 260, Arizona, in December 2003. Traffic volume, speed and vehicle type are measured by induction loops cut into the pavement.

Our primary focus in this analysis was determining the effect that varying traffic rates had on the probability of elk crossing SR 260. In addition to traffic, we identified four other factors that potentially influence elk movement near roads or are associated with higher elk-vehicle collision rates based on prior studies:

- *Traffic* (Rost and Bailey 1979, Witmer & deCelesta 1985, Czech 1991, Rowland et al. 2000, Wisdom et al. 2005, Gagnon 2006).

- *Presence of adjacent riparian-meadow habitat* (Ward 1976, Dodd et al. 2006, Dodd et al. 2007*b*, Manzo 2006).

- *Season* (Groot Bruinderink and Hazebroek 1996, Gunson and Clevenger 2003, Dodd et al. 2006).

- *Sex* (Marcum and Edge 1991, Gunson and Clevenger 2003, McCorquodale 2003, Dodd et al. 2006).

- *Time of day* (Groot Bruinderink and Hazebroek 1996, Haikonen and Summala 2001, Dodd et al. 2006).

We used Akaike's Information Criterion (AIC; Burnham and Anderson 2002) to select the most parsimonious model among a suite of 22 possible models that describe elk movements and crossing patterns. The models included all interactions up to three-way interactions. All models with interactions inherently included lower order terms and interactions, contributing to the total number of parameters (k). AIC values were adjusted for small sample size using the small sample AIC calculation (AIC_c). Once the best possible models were selected, for ease of interpretation, we converted them into probabilities and created a graphical representation of the probability of elk crossing SR 260 under these models.

8.3 RESULTS

Total monthly traffic for December 2003–June 2006 ranged from 120,129 to 330,011 vehicles and totaled 6,470,211 vehicles. Hourly traffic volumes during the peak elk movement period of 5:00 p.m.-8:00 a.m. ranged from 1–1,514 vehicles/hour and averaged 300 vehicles/hour (95% CI = 296, 304).

Our distribution analysis was based on 38,709 GPS relocations recorded within 2,000 ft of the highway between 5:00 p.m.-8:00 a.m. Frequency distributions of combined probabilities showed a shift in distribution away from the highway at increasing traffic volume, with the mean probability of an elk coming within 660 ft of the highway approximately 40% at fewer than 100 vehicles/hour and dropping to less than 20% when traffic was 600 vehicles/hour (Figure 8.2).

Our highway crossing probability analysis was based on 15,608 movements that occurred within 800 ft of the highway, yielding 2,177 crossings). Forty of the 44 elk crossed the highway at least once and were included in the analysis. Elk traveled almost twice the distance during crossings ($\bar{x}$ = 1532 ft., 95% CI = 1,470, 1,595 ft.) than during non-crossing movements ($\bar{x}$ = 830 ft, 95% CI = 814, 846 ft)

Our AIC model selection process yielded only one model that was supported under the AIC criteria ($\Delta AIC_c < 10$); this model included the three-way interaction among traffic volume, riparian-meadow habitat, and season (Table 8.1). For ease of interpretation we converted this model into probabilities under different scenarios and graphically displayed the probability of crossing for each traffic-meadow-season combination using these equations (Agresti 1996; Figure 8.3). The next closest models incorporated the interactions of traffic volume, riparian-meadow habitat, and time of day, followed by interactions of traffic rate, season, and time of day (ΔAIC_c = 13 and 21 respectively). Among the models that contained individual factors, traffic rate was the most influential model in determining crossing probability; however this factor alone was not supported under the model selection process (Table 8.1).

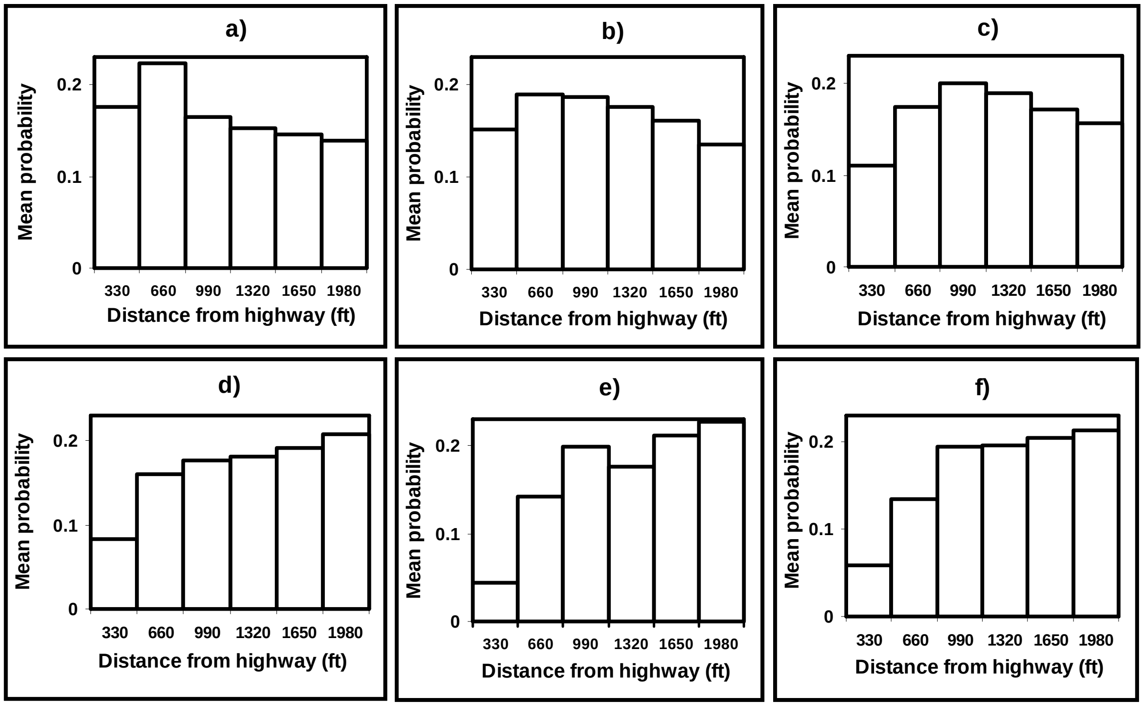

Figure 8.2. Mean probability that Global Positioning System (GPS)-collared elk (*n* = 44) occurred within each 330-ft distance band from State Route (SR) 260, Arizona, at varying traffic volumes: a) <100, b) 100-200, c) 200-300, d) 300-400, e) 400-500, f) >600 vehicles/hr. Our probabilities were determined from elk GPS telemetry and traffic counting conducted along SR 260 from 2003–2006.

8.4 DISCUSSION

8.4.1 Traffic volume and elk distribution

Studies of roadways with lower traffic volumes than SR 260 have documented that elk move away from areas with roads (Perry and Overly 1976; Lyon 1979, 1983; Rost and Bailey 1979; Witmer and deCelesta 1985; Rowland et al. 2000; Wisdom et al. 2005) and their movement increases adjacent to roads with increasing traffic volumes (Wisdom 1998, Johnson et al. 2000). Likewise, studies of these low-volume roads demonstrated that elk were often farther from roads during the day and came nearer roads during the night (Wisdom 1998, Ager et al. 2003), suggesting a short-term temporal response to lower nighttime traffic volumes. All of these studies examined roads with traffic volumes less than 10% of that experienced by elk along the highway in our study area. The consistent effect of low traffic volume roads on elk distribution logically led to the hypothesis that "persistent road-mediated disturbance may lead to permanent shifts in habitat use by elk" (Rowland et al. 2000:681). However, in spite of the much higher traffic volume on the highway we studied, we did not find a permanent shift away from the highway. Instead, elk responded to fluctuations in traffic volume by shifting away from the highway at high traffic volumes and returning to utilize areas near the highway when traffic volume was relatively low. Our results are consistent with the observation that 45% of more than 100,000 relocations of 33 radio-collared elk from an earlier phase of our project occurred within 0.6 mi of SR 260 (Dodd et al. 2007*b* and Section 6).

Table 8.1. Parameters for the only supported model (best model) of 22 possible for the probability of 40 elk crossing State Route (SR) 260, Arizona, using Akaike's Information Criterion (AIC), and its comparison to individual factors and the null model, -2 log-likelihoods, number of parameters (k), AIC adjusted for small sample sizes (AIC_c), AIC_c difference (ΔAIC_c), and Akaike weights (w_i). Our models were developed from elk Global Positioning System telemetry and traffic counting conducted along SR 260 from 2003–2006.

Model	-2 Log likelihood	k	AIC_c	ΔAIC_c	w_i
Best model					
Meadow-traffic-season	6,198	8	6,219	0	0.998
Individual factor models					
Traffic	6,263	2	6,267	49	<0.001
Meadow	6,269	2	6,273	55	<0.001
Time	6,276	2	6,280	62	<0.001
Season	6,278	2	6,282	68	<0.001
Sex	6,303	2	6,303	89	<0.001
Null model	6,303	1	6,305	86	<0.001

The pattern of elk distribution with fluctuating traffic that we documented is broadly consistent with models of roads resulting in reduced "habitat effectiveness" near roads (Lyon 1979, 1983). Habitat effectiveness is defined as "percentage of available habitat that is usable by elk outside the hunting season" (Lyon and Christensen1992:4). The "availability" of habitat within 660 ft of the highway, as measured by probability of elk presence, was clearly reduced at high traffic volumes. However, the fact that elk returned to use these areas when traffic volumes were low indicates that the relative reduction in habitat effectiveness would depend on the total amount of time each traffic volume was experienced. As a result, modeling of habitat effectiveness near highways with traffic volumes like those we studied should consider elk responses to traffic volume fluctuations, as has been suggested for lower volume roadways (Wisdom et al. 2005). Two factors may explain why elk in our study showed only temporary movement away from the highway: 1) elk that live near roadways with higher traffic may have a higher tolerance for traffic volumes, and 2) the riparian-meadow habitat and water sources along this highway may be of greater importance to elk at our site due to the relative rarity of these resources. (Dodd et al. 2006, Manzo 2006).

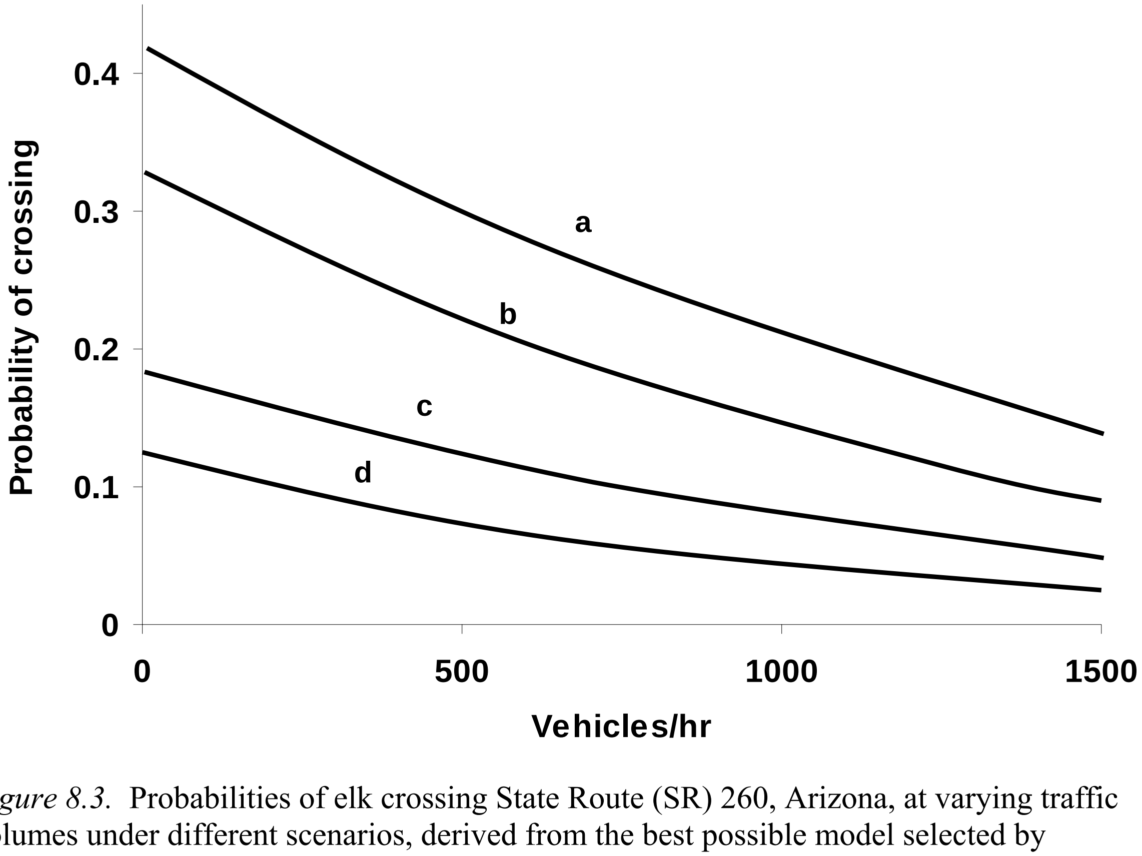

Figure 8.3. Probabilities of elk crossing State Route (SR) 260, Arizona, at varying traffic volumes under different scenarios, derived from the best possible model selected by Akaike's Information Criterion. Our scenarios include: a) spring or fall season with meadow present, b) spring or fall season with no meadow present, c) winter or summer season with meadow present, and d) winter or summer season with no meadow present. Probabilities were computed from 44 elk fitted with Global Position System collars and traffic counting conducting along SR 260 from 2003–2006.

8.4.2 Traffic volume, probability of highway crossing and highway permeability

As traffic volume increased from zero to 1500 vehicles/hour, the probability of highway crossings declined by approximately 20%. However, the effect of traffic volume on crossing probability was strongly influenced by both season and proximity to riparian-meadow habitat. We hypothesize that the influence of these two factors is due to their effect on the motivation for animals to cross the highway, and therefore their tendency to tolerate higher traffic volumes while crossing. Riparian-meadow habitats are heavily used by elk in this area, particularly in the spring when forage growth is most vigorous (Dodd et al. 2006, 2007*a, b* and Sections 4 and 6). As a result, part of the interaction between season and traffic volume may have been due to increased attractiveness of meadows in spring. However, a portion of the elk in our study also moves across the highway in both fall and spring as they migrate between summer and winter ranges. The elevation gradient across our study area is extremely steep, so migration can be relatively short, with animals summering on one side of the highway and wintering on the other, and yet remaining relatively close to the highway throughout the year. Other animals we tracked did not show these migratory movements, and the low probability of crossing during winter and summer likely reflects the combination of the absence of strong uni-directional movements by migrants and the tendency of "resident" animals to be just as likely to move along either side of the highway as to cross it.

Although bulls have higher sensitivity to roads than cows (Marcum and Edge 1991, McCorquodale 2003), our analysis did not indicate that sex was an important factor in predicting crossing probabilities. This difference may have been due to the close proximity of the highway to the riparian-meadow habitat apparently so important to elk in our study area. For example, Dodd et al. (2007*b* and Section 6) found that although riparian-meadow habitat made up only 4% of the available habitat in our study area, roughly 50% of bull locations occurred in these habitats during certain times of year.

Overall, our data indicate that the effect of traffic volume on the probability of highway crossing varied with landscape. Animals accessing rich foraging areas, like riparian meadows, or making seasonal movements were more likely to cross at higher traffic volumes. As a result, the effect of highways with similar traffic volumes may differ depending on how the location of the highway interacts with important resources and movement corridors. Traffic volume on a highway that intersects movement corridors between winter and summer seasonal ranges, for example, may reach higher levels before elk cease crossing compared to a highway that lies parallel to the corridor. A counter-intuitive prediction from this hypothesis is that highway impermeability would be reached at lower traffic volumes on highways that appear to have the smallest impact on elk access to important resources.

8.4.3 Elk distribution and collisions

The spatial response of elk to traffic volume that we documented indicated that elk were more likely to use resources near the highway when traffic volumes were lower, thus potentially increasing the probability of collisions with vehicles. It was not uncommon in our study to see elk feeding in the median or directly alongside the road where plant growth was enhanced by water runoff and artificial seeding to control erosion. This may explain in part why collisions between elk and vehicles on this highway occurred more frequently on weekdays, when traffic volume was low, compared to weekends (Dodd et al. 2006). This pattern contrasts with studies of elk (Gunson and Clevenger 2003) and white-tailed deer (Allen and McCullough 1976) in which the number of collisions were highest on weekends when traffic volume was higher. In these cases, the most effective mitigation measure may be fencing (Falk et al. 1978, Clevenger et al. 2001, Farrell et al. 2002)

While collisions during relatively low traffic volume periods may be due to elk that moved nearer the highway to forage along the shoulder or median, collisions during high traffic volume periods may be more likely either during migration, when elk make longer-distance movements to access seasonal ranges, or when elk that have moved farther from the highway to avoid higher traffic volumes make long-distance, directed movements to access the riparian-meadow habitat common along this stretch of highway. Given the potential for wildlife crossing structures to safely convey animals across highway corridors (Foster and Humphrey 1995, Gloyne and Clevenger 2001, Clevenger and Waltho 2000, 2005; Plumb et al. 2003; Dodd et al. 2006, 2007*a* and Section 4; Gagnon et al. 2006), our data indicate that placing these structures near meadows could allow elk to pass safely to and from these areas in both migratory and non-migratory seasons, thereby reducing the probability of elk-vehicle collisions at high traffic volumes.

Although the well-documented avoidance of low traffic volume roads by elk suggests even greater or permanent movement away from higher traffic volume highways, our results indicate that elk still utilized areas near the highway, though habitat effectiveness was reduced at high traffic volumes. As a result, models of habitat effectiveness for elk living near highways should consider both the temporal pattern of traffic volume and how elk respond to those traffic fluctuations. Likewise, the strong interaction between traffic volume, season and proximity to meadows on the probability of highway crossing by elk indicates that the relative impermeability of highways to elk due to traffic volume depends on where the highway is located relative to other important habitats. Relatively low traffic volumes may deter highway crossings in areas of relatively uniform habitat, while animals may continue to cross highways at relatively high traffic volumes when those highways separate animals from preferred seasonal or daily resources. As a result, analyses of the impact of traffic volume on highway crossing by elk must consider the larger landscape context. Finally, both the tendency for elk to shift closer to the highway at lower traffic volumes, and the tendency to cross the highway at higher traffic volumes during migratory periods or near meadows, could increase the potential for elk-vehicle collisions. As a result, attempts to identify patterns between elk-vehicle collisions and traffic volume may be confounded by these two contrasting behavioral responses to traffic. Given the potential for wildlife crossing structures to reduce wildlife-vehicle collisions, placing these structures near meadows could allow elk to pass safely to and from these areas in both migratory and non-migratory seasons, thereby reducing the probability of elk-vehicle collisions in these areas at all traffic volumes.

9.0 CHARACTERISTICS OF ELK-VEHICLE COLLISIONS AND COMPARISON TO GLOBAL POSITIONING SYSTEM-DETERMINED HIGHWAY CROSSING PATTERNS

9.1 INTRODUCTION

Wildlife-vehicle collisions cause human injuries and deaths, tremendous property damage (Figure 9.1), 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 wildlife-vehicle collisions have been conducted, most focusing on deer (Reed and Woodard 1981, Bashore et al. 1985, Romin and Bissonette 1996b, Hubbard 2000). Only recently have studies specifically addressed elk-vehicle collision patterns (Gunson and Clevenger 2003, Biggs et al. 2004).

Figure 9.1. Bull elk killed in elk-vehicle collision along the Christopher Creek section of State Route 260, Arizona, (left) and a vehicle that struck an elk and sustained substantial property damage and injured the driver.

Insights gained from such studies have been instrumental in developing strategies to reduce wildlife-vehicle collisions (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 wildlife-vehicle collisions 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 collisions (Reed and Woodard 1981, Ward 1982, Clevenger et al. 2001). Though valuable, no study has investigated or validated the relationships between wildlife-vehicle collisions and the spatial and temporal crossing patterns of wildlife involved in collisions with vehicles. In fact, Barnum (2003) reported that wildlife-vehicle collision data were not useful in identifying crossing zones, largely due to inaccurate reporting. The application of global positioning system (GPS) telemetry to wildlife movement studies has become increasingly popular, cost-effective, and reliable (Rodgers et al. 1996) 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. 2007*b* and Section 6).

The objective of our study was to investigate spatial and temporal patterns of elk-vehicle collisions along State Route (SR) 260. The study area is currently being reconstructed in phases and will have numerous passage structures and associated ungulate-proof fencing to limit crossings at grade and funnel animals toward underpasses. The incidence of elk-vehicle collisions here was a key factor used in the planning and setting of priority of passage structure construction along this highway. As this highway is being upgraded in phases, we can compare elk-vehicle collisions associated with the highway at various stages of construction (e.g., before-, during, and after-construction), as well as validate the priority of reconstruction of the highway sections. We sought to compare spatial and temporal patterns of elk-vehicle collisions to elk highway crossings determined by GPS telemetry as a means to validate the management utility of elk-vehicle collision data in developing strategies to reduce collisions and promote passage. Lastly, we assessed the influence of traffic volume on temporal patterns of elk-vehicle collisions and elk highway crossings.

9.2 METHODS

This aspect of our project was conducted along the entire 17-mi study stretch of SR 260 (Figure 3.1).

9.2.1 Wildlife-vehicle collision tracking

We used two sources of data on wildlife-vehicle collisions. Our primary source was a long-term statewide accident database maintained by the ADOT Data Management Section (ADOT database; Phoenix, AZ), that included data on wildlife-vehicle collisions. 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% of the reports and the remainder were made by other jurisdictions. As such, we considered this database to be a relatively consistent long-term accounting of wildlife-vehicle collisions. Records in this database have the date, time, and location (to the nearest 0.1 mi) of the collision, the wildlife species involved (genus only in the case of deer), and the reporting agency. Generally this database did not include sex and age data. We queried the database for wildlife-vehicle collisions that occurred in the study area (SR 260 between mileposts 259-278) from 1994-2006. This database was our basis for assessing long-term trends in wildlife-vehicle collisions and relationships to highway construction, as well as the proportion of total and single-vehicle accidents involving collisions with wildlife.

At the beginning of our project, we developed and disseminated a wildlife-vehicle collision tracking form for use by agencies and research project personnel to document all wildlife-vehicle collisions (including roadkills) along SR 260. This database incorporating the tracking form data reflected concerted efforts, especially by project personnel, to regularly search for and document wildlife-vehicle collisions along SR 260. Of the reports compiled for 2001-2006, 57.6% were submitted by DPS, most of which were also logged in the ADOT database. Arizona Game and Fish Department (AGFD) personnel accounted for the remainder (42.4%), none of which 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 a collision, species of deer, and road and weather conditions. Wildlife-vehicle collisions were recorded to the nearest 0.1 mi. We relied on this database to characterize the sex and age of wildlife involved in collisions, as well as assess the proportion of collisions that were logged in the ADOT database.

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

9.2.2 Elk-vehicle collision relationships to AADT and elk population estimates

We assessed the relationships of elk-vehicle collisions to AADT and elk population estimates for the management units encompassing our study area for 1994-2004, before substantial amounts of fencing were erected along the Christopher Creek section. AADT estimates were obtained from the ADOT Data Management Section and were calculated based on annual traffic sampling conducted along SR 260 midway though our study area (Control Road traffic sampling station).

Elk population estimates (pre-hunt) were obtained from the annual elk management summaries (1994-2005) for Game Management Units (GMU) 22 and 23 provided by AGFD Game Branch; we combined the estimates because 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 used the estimates as an index of relative population levels that fluctuate from year to year due to 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 2001-2005 to the bull:cow ratio of animals involved in elk-vehicle collisions (observed) during the same period using chi-square analysis.

We used multiple regression analysis to assess the relationship of elk-vehicle collisions to AADT and elk population estimates combined and partial regression analysis to assess the relative importance of independent variables by (Neter et al. 1996) linear regression. . From this analysis, we predicted potential elk-vehicle collisions based on varying AADT levels while holding elk population levels static.

9.2.3 Comparison of elk-vehicle collision by highway section and construction classes

We compared elk-vehicle collisions among highway sections by calculating mean collision rates (collisions/mi/year) to account for different section lengths. We used analysis of variance (ANOVA; Hays 1981) to assess differences in mean collision rates among sections, with separate analyses for all years and for pre-construction years only. For significant ANOVA tests, we assessed pairwise differences in mean collision rates with Tukey tests for unequal sample sizes (Hays 1981). We compared mean collisions among highway construction classes (before-, during, and after-reconstruction) using analysis of covariance (ANCOVA; Hays 1981). We controlled for AADT effects (covariate) in our ANCOVA analysis. Where significant results were obtained in our ANCOVA, post hoc pairwise comparisons were done using a Tukey test for unequal sample sizes to assess differences in mean elk-vehicle collisions among construction classes.

9.2.4 GPS telemetry assessment of elk highway crossings

We put Global Positioning System (GPS) collars on elk at 10 sites along SR 260, and analyzed elk highway crossing patterns as detailed in Section 6.0 and in Dodd et al. (2007*b*). We limited our analysis to our first phase of GPS telemetry as it constituted a better baseline against which to compare elk crossing patterns to elk-vehicle collisions. Under our first phase, reported in Section 6.0, we trapped with fairly consistent effort across all sections whereas our second phase of telemetry focused on the Christopher Creek section. Also, midway through our second phase of telemetry research, much of the Christopher Creek section was fenced thus affecting baseline crossing and collision patterns.

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 by 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, as described in Section 6.0 and Dodd et al. (2007*b*). We also used this test to compare the elk crossing frequency distributions for uncorrected versus weighted crossing distributions for all highway segments and sections.

9.2.5 Comparison of elk-vehicle collision and elk highway crossing patterns

We used linear regression to assess the spatial association between the frequency of elk-vehicle collisions 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 collisions to crossings at the 0.1 mi segment scale, and aggregated the data to

0.3 mi, 0.6 mi, 1.0 mi, 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 collisions to crossings.

Due to the important role that riparian-meadow habitats played in influencing elk highway crossings along SR 260 (Dodd et al. 2007*b* and Section 6), we assessed the association between proximity to riparian-meadow habitats and collisions and highway crossings. We used linear regression to measure the association between collisions at the highway section and 0.6 mi scales with the number of 0.1-mi segments in which riparian/meadow habitat was located within 0.15 mi.

We conducted comparisons of elk-vehicle collisions and elk crossings by month, day, and time (2-hour intervals), and used chi-square tests to compare observed versus expected collisions and elk crossings for each temporal parameter. Also, assuming that the proportion of elk crossings by month, day, and time reflected the expected proportion in which collisions would occur, we compared the proportion of elk crossings (expected) to the actual proportion of collisions that occurred (observed) using chi-square testing. Comparisons by time used only crossings determined from GPS fixes acquired 1.5 or two hours apart; we used the interval midpoint as the time for comparisons with wildlife-vehicle collisions. We compared deer-vehicle collisions to elk-vehicle collisions 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 wildlife-vehicle collision frequency × daily AADT factors was used to account for the influence of traffic volume.

We defined high elk-vehicle collision and elk crossing (weighted) sections along SR 260 at the 0.6-mi 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 elk-vehicle collision 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 elk-vehicle collision or crossing level:

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

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

We assessed the number of elk fitted with GPS collars that were involved in collisions, using elk collared during both phases of our GPS telemetry research (Sections 6.0 and 7.0). We compared the actual versus expected number of elk collared and killed in collisions by the mean individual elk frequency of highway crossings using chi-square analysis, using the following elk highway crossing frequency classes:

- *Infrequent crossers* – fewer than 0.2 highway crossings/day.
- *Intermediate frequency crossers* - 0.2–0.4 highway crossings/day.
- *Frequent crossers* - more than 0.4 highway crossings/day

All statistical tests were performed using the program Statistica® by Statsoft, Inc.(1994). Results were considered significant at $P \leq 0.05$. Mean values were reported with ± 1 SE.

9.3 RESULTS

From 1994 to 2006, 462 wildlife-vehicle collisions were recorded in the ADOT database (Table 9.1), for an average of 36.2 collisions/year (±2.7): 83.7% involved elk and 14.4% involved deer (Table 9.1). Also, 2 black bears, 3 mountain lions (*Puma concolor*), and one javelina (*Tayassu tajacu*) were killed in collisions (Table 9.1).

Between 2001 and 2006, we documented 337 wildlife-vehicle collisions (Table 9.2) compared to 228 in the ADOT database (Table 9.1); elk accounted for 86.3% (Table 9.2) and deer 12.2%. Of the classified elk, cows were involved in collisions more than 5 times as frequently as bulls, and adult elk accounted for 75.8% of the collisions (Table 9.2). Of the classified deer, 63.0% were white-tailed deer versus 37.0% mule deer. Two-thirds of all collisions were recorded in both the ADOT and our databases. A mean of 68.6% of our elk-vehicle collisions were recorded in the ADOT database (Table 9.3), and ranged from 37.2% (2006) to 96.7% (2001).

Over half (51%) of the 704 single-vehicle accidents recorded by DPS from 1994 and 2005 involved wildlife (Table 9.4). The Christopher Creek section had the highest proportion of single-vehicle accidents caused by wildlife (0.58), the Preacher Canyon section the lowest (0.38).

9.3.1 Elk-vehicle collision relationships to AADT and elk population estimates

From 1994-2004, wildlife-vehicle collisions increased at a mean rate of 4.7%/year, while AADT increased 11.2%/year up to 2002, with a 38.8% increase in AADT between 2002 and 2003 alone, and 17.8% overall (Table 9.1). The elk population estimate for the management units encompassing our study area ranged from 1,488 to 2,243 elk (Table 9.1).

Our association between elk-vehicle collisions and AADT accounted for 31% of the variation in these collisions ($r = 0.559$, $r^2 = 0.313$, $P = 0.074$, $n = 11$), while the association between elk-vehicle collisions and elk population estimates explained only

Table 9.1. Frequency of wildlife-vehicle collisions by species and average annual daily traffic (AADT) volume for State Route 260, Arizona, and elk population estimates for management units adjacent to SR 260, for the period 1994–2006. Wildlife-vehicle collision data reflect ADOT/Department of Public Safety records only, allowing for comparison among years.

	No. wildlife-vehicle collisions[a]					Elk
Year	Total	Elk	Deer	Other[b]	AADT[c]	population[d]
1994	29	20	9	0	3,123	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	5,100	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	7,200	1,685
2005	38	39	2	0	7,500	2,243
2006	29	27	1	1	N/A	N/A
Mean (±SE)	36.2 (2.7)	29.8 (2.3)	5.2 (0.8)	1.2 (0.4)	5,149.6 (35.9)	1,694.1 (53.8)

[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

2% of the variation ($r = 0.151$, $r^2 = 0.023$, $P = 0.657$, $n = 11$). However, when we incorporated both AADT and elk population estimates into a multiple regression model, the relationship accounted for 74% of the variation in elk-vehicle collisions ($r = 0.861$, $r^2 = 0.741$, $P = 0.004$, $n = 11$); partial regression coefficients for AADT (1.10, $P = 0.001$) and elk population estimates (0.846, $P = 0.007$) were both significant. The equation for our elk-vehicle collision regression function was:

$$\text{Elk-vehicle collisions} = -158.0 + (\text{AADT} \times 0.005) + (\text{elk population} \times 0.098)$$

In addition to AADT and elk population levels influencing the annual incidence of elk-vehicle collisions, individual highway crossing variation and apparent tolerance to traffic among elk appeared to influence the likelihood of elk being involved in a collision. Of 63 elk fitted with GPS telemetry collars between 2002-2006, 8 (12.7%) were killed in collisions (Table 9.5). However, when we considered the proportion of elk within highway crossing frequency classes, the 14 elk (22.2% of all collared elk) in the frequent crosser class accounted for a highly disproportionate 87.5% of all collisions involving collared elk (Table 9.4; $\chi^2 = 14.2$, df = 2, $P < 0.001$); 50% of the elk in this crossing class were killed in collisions compared to only 2% of 49 collared elk in the other two classes (Table 9.5).

Table 9.2. Number of animals killed in wildlife-vehicle collisions along State Route 260, Arizona, by species documented by DPS and AGFD between 2001–2006, with age and sex of classified animals and proportion of classified animals.

	No. of animals killed in wildlife-vehicle collisions										
		Sex (% of total classified)[a]				Age (% of total classified)[a]					
Species	All	Female		Male		Adult		Yearling		Young	
Elk	291	154	(83.7)	30	(16.3)	135	(75.8)	21	(11.8)	22	(12.3)
WT[b] deer	17	4	(28.6)	10	(71.4)	11	(84.6)	2	(15.4)	1	(7.7)
Mule deer	10	9	(90.0)	1	(10.0)	8	(80.0)	1	(10.0)	1	(10.0)
Deer[c]	14	5	(83.3)	1	(16.7)	5	(83.3)	1	(16.7)	-	-
Black bear	2	1	(50.0)	1	(50.0)	1	(50.0)	1	(50.0)	-	-
Mtn. lion	3	1	(50.0)	1	(50.0)	2	(66.6)	0	-	1	(33.3)

[a] Unclassified records account for differences between totals and number by sex and age
[b] WT = white-tailed deer [c] Species of deer not specified

9.3.2 Comparison of elk-vehicle collisions by highway section and construction class

The location and frequency of elk-vehicle collisions across all the 0.1-mi segments of SR 260 were not randomly distributed (Kolmogorov-Smirnov test, $d = 0.13$, $P < 0.005$; Figure 9.2). They ranged from 0 to 1.2/segment/year (mean = 0.15 ±0.02) for the period 1994-2006. The mean elk-vehicle collision rate for all SR 260 sections for this period was 1.6 collisions/mi/year (±0.02; Table 9.6); the Preacher Canyon section had the highest mean collision rate of the five sections (2.6/mi/year), followed by the Christopher Creek section (2.1/mi/year). When we considered before-reconstruction mean collision rates, the basis for ADOT's prioritization of reconstruction phasing, we found that collisions differed among sections (ANCOVA $F_{4, 43} = 11.7$, $P < 0.001$). The Preacher Canyon section, the first reconstructed, had the highest collision rate (2.6/mi/year) followed by the Christopher Creek section (1.7/mi/year), which were both higher than means for the Little Green Valley (0.2/mi/year; both $P < 0.001$) and Doubtful Canyon (0.3/mi/year; Preacher Canyon section $P = 0.018$ and Christopher Creek section $P = 0.005$) sections. Also, the mean collision rate before reconstruction for the Kohl's Ranch section (1.4/mi/year) was higher than that for the Little Green Valley section ($P = 0.012$).

Table 9.3. Frequency of elk-vehicle collisions by State Route 260 highway section, Arizona, for the period 2001–2006 by DPS and AFGD, and a comparison of the total elk-vehicle collisions to the total in the ADOT database (see Table 9.1) for the same period.

	No. of EVC by highway section						Percentage of
Year	PC[a]	LGV[b]	KR[c]	DC[d]	CC[e]	Total	ADOT database
2001	10	1	5	2	3	21	92.5
2002	12	0	1	3	19	35	89.7
2003	10	1	5	4	19	39	76.7
2004	12	0	6	3	52	73	54.2
2005	14	2	10	9	12	47	61.1
2006	12	3	6	9	10	40	37.2
Mean EVC/year (±SE)	11.7 (0.6)	1.2 (0.5)	5.5 (1.2)	5.0 (1.3)	19.2 (7.0)	42.5 (7.0)	68.6 (8.8)
Section length (mi)	3.0	2.5	4.0	3.0	4.5	17.0	
Mean EVC/mi/year	3.9	0.5	1.4	1.7	4.3	2.5	

Highway sections: [a]Preacher Canyon section [b]Little Green Valley section
[c]Kohl's Ranch section [d]Doubtful Canyon section [e]Christopher Creek section

We found that the mean of elk-vehicle collisions differed among highway construction classes (ANCOVA $F_{2,61} = 17.5$, $P < 0.001$; Table 9.7). The collision mean during highway reconstruction (11.6 collisions/year) was higher than the mean before (4.4 collisions/year; $P = 0.003$) and after reconstruction (6.5 collisions/year; $P = 0.044$). For the Preacher Canyon section, the longest for which we conducted after-reconstruction monitoring, we found no differences (ANCOVA $P = 0.762$) among mean elk-vehicle collisions before (7.7, $n = 6$), during (8.0, $n = 2$), and after construction was completed (7.7, $n = 3$; Figure 9.3). We did find differences on the Christopher Creek Section among reconstruction classes ($F_{2,9} = 6.4$, $P = 0.019$); the collision mean during construction (19.7/year, $n = 3$) was more than 2.5 times larger than the before-construction mean (7.6/year, $n = 8$; $P = 0.034$), and 3.5 times higher than the after construction mean ($P = 0.042$). In our database (Table 9.3), the single-year increase in collisions on the Christopher Creek section during reconstruction was particularly dramatic, increasing more than 2.5 times, from 19 in 2003 to 52 in 2004, the year after the highway was opened to traffic but before ungulate-proof fencing was completed (Figure 9.3). Though after-reconstruction collisions for the Kohl's Ranch section were ⅓ of the before- and during-reconstruction mean levels (Table 9.7), the single year after-reconstruction monitoring was insufficient to provide meaningful inference for this highway section.

Table 9.4. Proportion of single-vehicle accidents involving wildlife by State Route 260 highway section, Arizona, 1994–2005.

	Proportion of single-vehicle collisions involving wildlife by highway section					
Year	PC[a]	LGV[b]	KR[c]	DC[d]	CC[e]	All sections
1994	0.29	0.44	0.33	0.79	0.36	0.46
1995	0.33	0.36	0.29	0.67	0.73	0.56
1996	0.50	0.70	0.67	0.83	0.55	0.58
1997	0.22	0.64	0.50	0.40	0.67	0.53
1998	0.33	0.79	0.53	0.63	0.65	0.58
1999	0.29	0.79	0.50	0.50	0.72	0.58
2000	0.30	0.33	0.27	0.22	0.44	0.31
2001	0.36	0.60	0.60	0.40	0.43	0.48
2002	0.56	0.00	0.42	0.50	0.68	0.53
2003	0.45	0.23	0.30	0.44	0.46	0.39
2004	0.27	0.60	0.21	0.42	0.76	0.52
2005	0.60	0.80	0.43	0.45	0.55	0.54
Mean	0.38	0.52	0.42	0.52	0.58	0.51

Highway sections: [a]Preacher Canyon section [b]Little Green Valley section
[c]Kohl's Ranch section [d]Doubtful Canyon section [e]Christopher Creek section

9.3.3 Cost-benefit of measures to reduce elk-vehicle collisions

We used the multiple regression model in Section 9.3.1 to compare documented to predicted elk-vehicle collisions for the period since SR 260 has undergone reconstruction (2001-2006). Since the first section was completed in 2001, and given increasing AADT levels, 2006 was the first year that the various underpass and fencing measures on the Preacher Canyon (completed late 2001; Figure 9.3), Christopher Creek (completed late 2004; Figure 9.3), and Kohl's Ranch (completed early 2006) sections have resulted in collisions dropping below the predicted level (Figure 9.4). During the same period, elk-vehicle collisions on our two control sections have increased by over 400% (Figure 9.3), which we attribute to increased AADT levels. As additional measures are implemented (e.g., fencing the remaining 2.7 mi of the Preacher Canyon section by early 2007, closing the 0.2-mi gap along the Christopher Creek section) and the benefits of measures to the Kohl's Ranch section are fully realized, and we anticipate that actual collisions will drop even more below predicted levels.

We used our regression model in Section 9.3.1 to predict elk-vehicle collisions under increasing AADT levels while holding elk population levels constant at current levels (Figure 9.5). It is anticipated that AADT along SR 260 will rise beyond 10,000, the theoretical level at which traffic presents a near-total barrier to wildlife. Collisions with vehicles are predicted to actually decrease as fewer animals cross the highway (Mueller and Berthoud 1997). Not only will underpasses and fencing prove crucial to promoting wildlife permeability across SR 260 with increasing AADT (see Section 7.0), but these measures will prove instrumental in promoting highway safety. Since 2004, the benefit realized in strategically fencing portions of the Christopher Creek and Kohl's Ranch sections has netted a 45% reduction in elk-vehicle collisions by 2006 (Table 9.3). The entire Preacher Canyon section was fenced in March 2007, which is anticipated to prevent more than 10 elk-vehicle collisions/year over 2006 levels, dropping total annual elk-vehicle collisions to approximately 30/year, or a near 60% reduction; further measures on the Christopher Creek section, and reconstruction of the Little Green Valley and Doubtful Canyon control sections in the near future could increase the reduction in elk-vehicle collisions.

Huijser et al. (2006) conducted an extensive review of costs associated with wildlife-vehicle collisions including costs associated with vehicle property damage, human injuries and fatalities, removal and disposal of carcasses, and loss of recreational value of killed animals. They reported the cost of each elk-vehicle collision to be $17,100. The reduction from 73 collisions documented in 2004 to 40 in 2006 would result in an annual benefit of $564,300; with an anticipated reduction to 30 collisions in 2007, once the Preacher Canyon section is fenced, the benefit would increase to $735,300/year. Over a 20-year period, the benefit from the SR 260 measures implemented to date would approach $15,000,000 (in 2006 dollars). Factoring in AADT, our regression model predicted that an additional 6 elk-vehicle collisions would occur for every increase of 500 AADT. Thus, with our 2004 baseline of 73 collisions with an AADT of 7,200 vehicles/day (Table 9.3), we theorize that approximately 80 collisions would have occurred at an AADT of 8,500 without the measures to limit elk-vehicle collisions that have been implemented to date, and 90 by the time AADT approached

10,000 vehicles/day (Figure 9.5). At 8,500 vehicles/day, the annual benefit was projected at $850,000/year, and $950,000/year once AADT hit 10,000 vehicles/day (Figure 9.5).

9.3.4 Comparison of elk-vehicle collision and elk highway crossing patterns

From our 33 elk to which GPS collars were affixed under Phase I of our telemetry research (Section 6.0, Dodd et al. 2007*b*), we accrued 101,506 GPS fixes and determined that they crossed SR 260 3,057 times (Figure 6.5). The number of different elk crossing at each highway segment ranged from 0-8, and averaged 3.3. Our weighted crossing frequencies considering SDI (Figure 9.2) for all segments exhibited significant shifts in crossing patterns compared to those without SDI (Figure 6.5; Kolmogorov-Smirnov test, $d = 0.22$, $P < 0.001$). Most apparent were differences for the Christopher Creek section, which had high SDI elevated crossings for many segments, some of the highest along the entire study area (Figure 9.2); weighted crossing frequency for the Christopher Creek section was 32% over the non-weighted crossings (Kolmogorov-Smirnov test, $d = 0.28$, $P < 0.01$). At the Preacher Canyon 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 (Figure 9.2), which better reflected the high diversity and frequency of elk crossings there. Even with the dramatic shift in crossing peaks for the Preacher Canyon section, weighted crossing frequency increased only negligibly (1.1%; Table 9.8), and the crossing patterns did not differ. Weighted and raw crossing distributions for the other three sections also did not differ

Table 9.5. Number of elk fitted with Global Positioning System (GPS) collars versus those that were killed in elk-vehicle collisions along State Route 260, Arizona, by highway crossing frequency class. Elk were collared under two phases of telemetry research conducted 2002–2006. Chi-square analysis compared the proportion of collared elk in each highway crossing frequency class to the proportion that were killed in elk-vehicle collisions.

Mean highway	Phase I elk[a]		Phase II elk[b]		All elk Phases I & II[c]			
crossings/day	No.	Killed	Elk	Killed	No.	(% total)	Killed	(% total)
<0.20	18	0	18	1	36	(58.1%)	1	(14.3%)
0.21-0.40	7	0	6	0	13	(21.0%)	0	(0%)
>0.40	7	4	7	3	14	(22.2%)	7	(87.5%)
All	32	4	31	4	63	(100.0%)	8	(100.0%)

[a] 2002–2004 (see Section 6.0) [b] 2004-2006 (see Section 7.0)

[c] Observed versus expected elk killed in vehicle collisions $\chi^2 = 14.2$, df = 2, $P < 0.001$

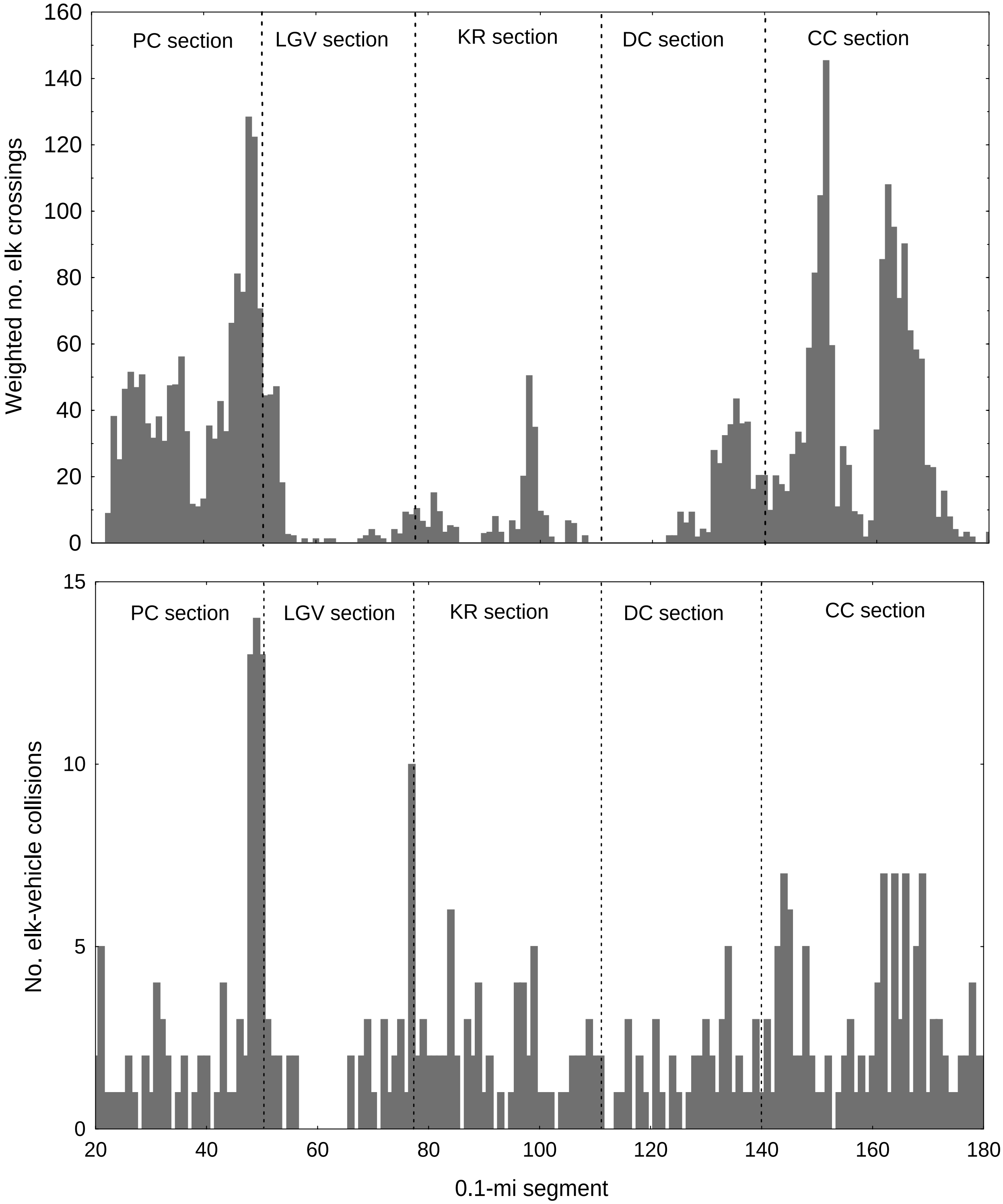

Figure 9.2. Number of elk-vehicle collisions (1994–2006) and weighted elk highway crossings for 33 elk fitted with Global Positioning System collars 2002–2004 by 0.1-mi segments and sections along State Route 260, Arizona.

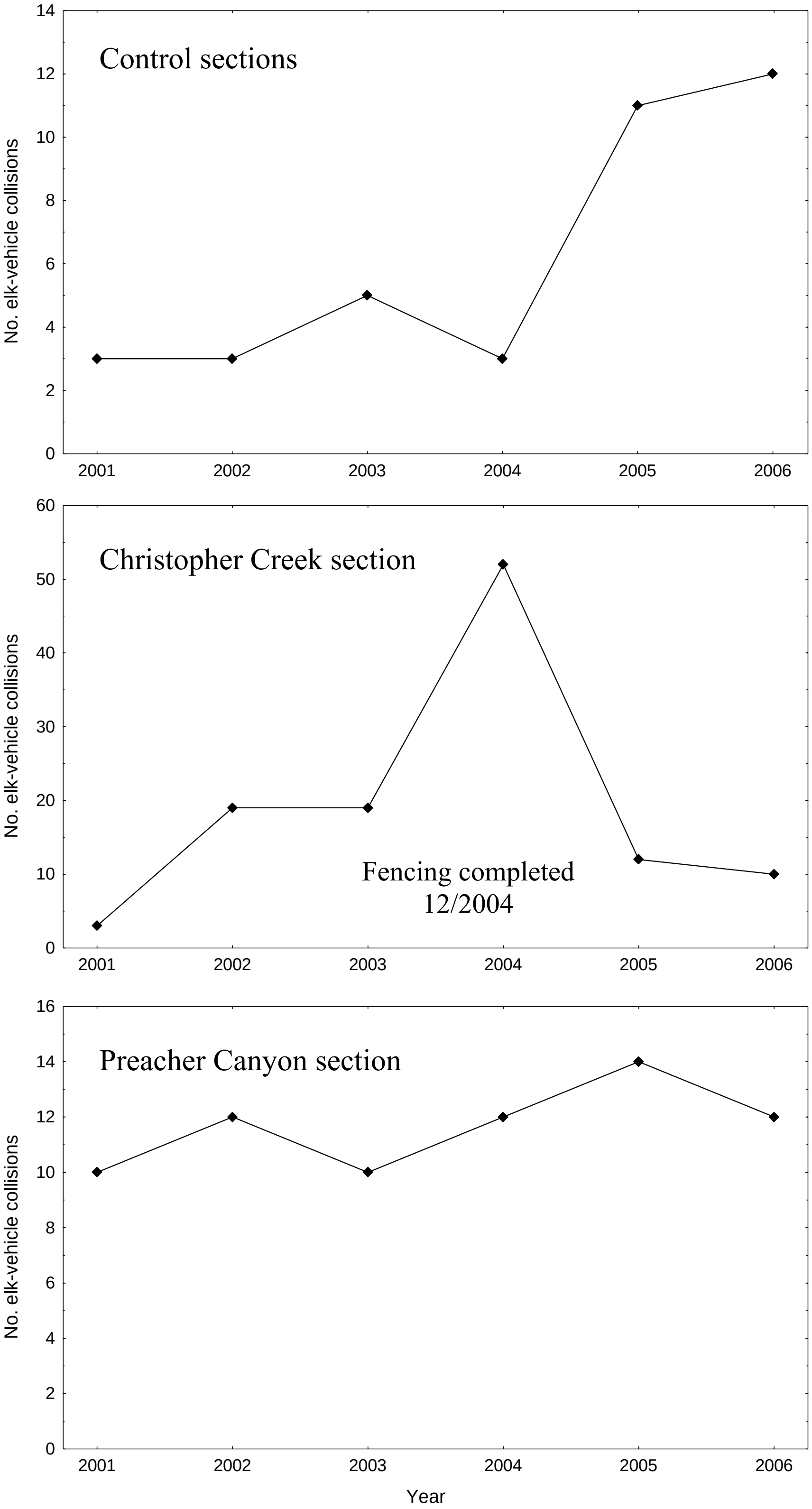

Figure 9.3. Number of elk-vehicle collisions recorded 2001–2006 on the Preacher Canyon (bottom), Christopher Creek (middle), and control sections (Little Green Valley and Doubtful Canyon) of State Route 260, Arizona. Note upward trend in on control sections while collisions on the Preacher Canyon section were static and declined on Christopher Creek section after fencing in 2004.

Table 9.6. Number of elk-vehicle collisions by State Route 260 highway section, Arizona, 1994–2006, and mean collisions/mi/year (±SE) for each section. Elk-vehicle collision data reflect ADOT/Department of Public Safety records only.

	No. of elk-vehicle collisions by State Route 260 section					
Year	PC[a]	LGV[b]	KR[c]	DC[d]	CC[e]	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	1	6	2	3	22
2002	9	0	1	3	18	31
2003	6	1	5	3	14	29
2004	5	0	2	2	24	43
2005	9	2	6	5	5	27
2006	9	3	2	5	6	25
Mean collisions/year	7.7	1.1	4.5	2.8	9.6	26.5
Section length (mi)	3.0	2.5	4.0	3.0	4.5	17.0
Mean collisions/mi/year (±SE)	2.6 (0.3)	0.4 (0.1)	1.1 (0.2)	0.9 (0.2)	2.1 (0.4)	1.6 (0.1)

Highway sections: [a]Preacher Canyon section [b]Little Green Valley section [c]Kohl's Ranch section [d]Doubtful Canyon section [e]Christopher Creek section

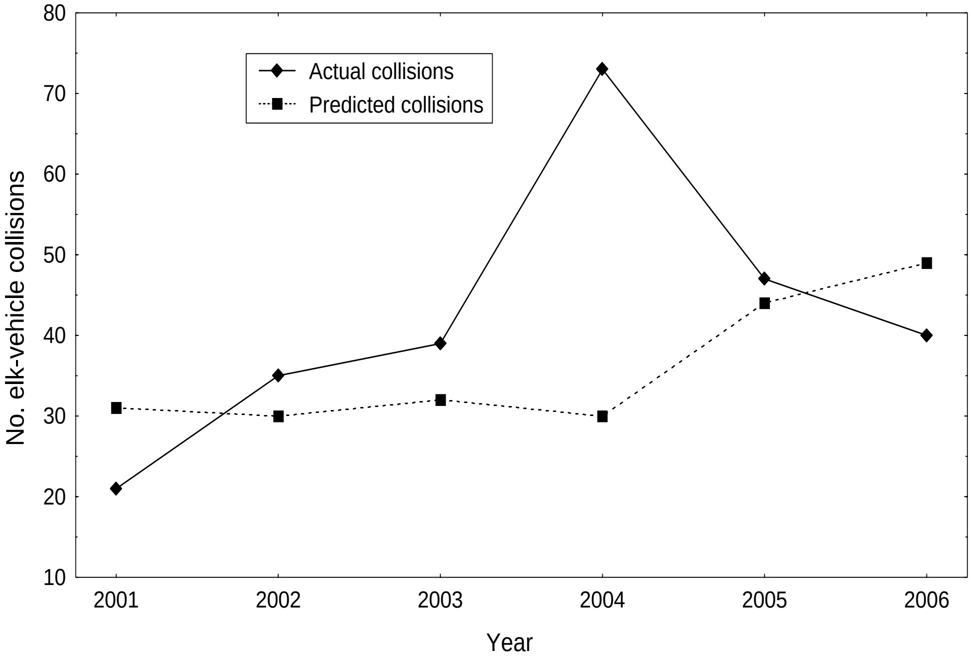

Figure 9.4. Actual elk-vehicle collisions recorded along State Route 260, Arizona, from 2001–2006, compared to levels predicted from our multiple regression equation using average annual daily traffic volume and elk population data.

Table 9.7. Dates of construction initiation and completion for SR 260 highway sections, Arizona, and mean number of elk-vehicle collisions (EVC) from 1994–2006 (±SE) by highway construction classes (before, during, and after reconstruction). Letters denote differences among means for the highway construction classes (ANCOVA).

Highway	Date reconstruction:		Mean EVC (±SE) by reconstruction class (*n* = years data)					
section	Started	Complete	Before		During		After	
PC	2000	11/2001	7.7 (1.3) A	*n* = 6	8.0 (2.0) A	*n* = 2	7.8 (1.0) A	*n* = 5
LGV	Control		0.4 (0.2)	*n* = 13				
KR	2002	3/2006	5.8 (0.1) A	*n* = 9	6.0 (0.6) A	*n* =3	2.0 (-) A	*n* = 1
DC	Control		0.9 (0.2)	*n* = 13				
CC[a]	2001	12/2004	7.6 (1.5) A	*n* = 8	19.7 (4.2) B	*n* = 3	5.5 (0.5) A	*n* = 2
All[b]			4.4 (0.5) A		11.6 (2.7) B		6.5 (0.9) A	

[a] ANCOVA differences among reconstruction classes F2, 9 = 6.4, P = 0.019

[b] ANCOVA differences among reconstruction classes F2, 61 = 17.5, P < 0.001

PC = Preacher Canyon   LGV = Little Green Valley   KR = Kohl's Ranch   DC = Doubtful Canyon   CC = Christopher Creek

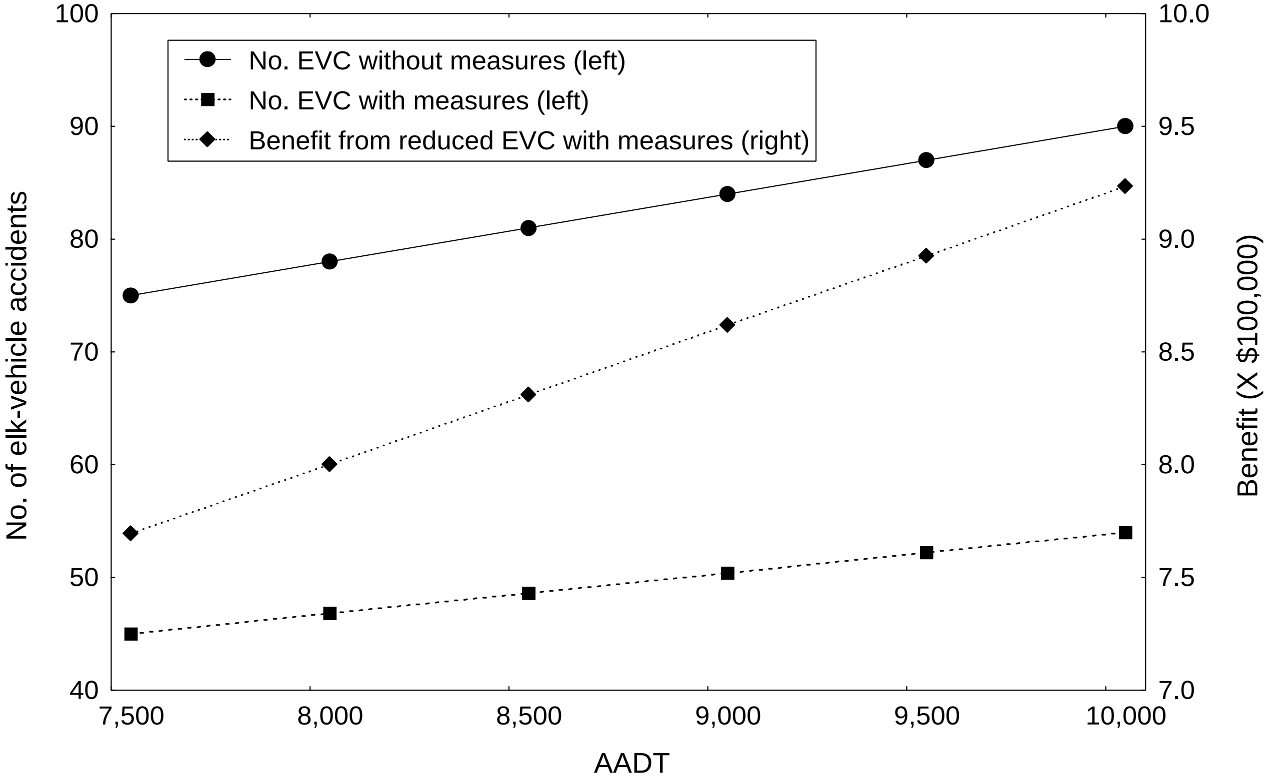

Figure 9.5. Number of elk-vehicle collisions along State Route 260, Arizona, by AADT levels with and without measures to reduce collision incidence of including underpasses and fencing assuming a 60% reduction in elk-vehicle collisions with measures, and the economic benefit associated with the difference in the number of elk-vehicle collisions at varying AADT .

Table 9.8. Summary of elk crossings, Shannon Diversity Index (SDI), and weighted crossings by highway section along State Route 260, Arizona, determined from 33 elk fitted with GPS telemetry collars, May 2002–April 2004.

Highway section (mi)		No. elk crossings (%)		Crossings/ mi	Mean SDI[a]	Weighted no. crossings[b] (%)		Weighted crossings/mi
PC	(3.0)	1,298	(42.4)	432.7	1.00	1,312	(37.1)	437.3
LGV	(2.5)	132	(4.3)	52.8	0.65	193	(5.5)	35.1
KR	(4.0)	212	(6.9)	53.0	0.75	237	(6.7)	59.2
DC	(3.0)	292	(9.5)	97.3	0.70	332	(9.4)	110.7
CC	(4.5)	1,070	(35.0)	237.8	1.07	1,451	(41.0)	322.4
All	(17.0)	3,057	(100.0)	179.8	0.71	3,534	(100.0)	118.6

[a] Shannon Diversity Index (Shannon and Weaver 1949)
[b] Weighted crossings = ∑ (no. of crossings/segment × SDI)

9.3.5 Spatial relationships between elk-vehicle collision and crossing patterns

The strength of the associations between elk-vehicle collisions and elk highway crossings increased as a function of increasing scale (Table 9.9). Our strongest association between collisions 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 0.1-mi segment scale for uncorrected crossings ($r = 0.396$, $r^2 = 0.156$, $n = 200$, $P < 0.001$). The relationships between collisions and weighted elk crossings accounted for an average of 16.2% more variation in collisions compared to uncorrected elk crossings (Table 9.9, Figure 9.6).

The associations between elk-vehicle collisions and weighted elk crossings at the 1.0-mi and 0.6-mi scales were comparable, with both explaining 70% of the variation in collisions (Table 9.9, Figure 9.6). However, the strength of the relationships diminished at scales below 0.6 mi; the amount of variation explained by thr relationships declined incrementally by more than 20% between each scale below the 0.6-mi level (Figure 9.6).

At the highway section scale, the number of 0.1-mi segments located within 0.15 mi of riparian-meadow habitat was strongly associated with elk-vehicle collisions ($r = 0.981$, $r^2 = 0.962$, $n = 5$, $P = 0.003$). 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 0.6-mi scale, the number of segments in proximity to riparian-meadow habitat was associated with both the frequency of collisions ($r = 0.751$, $r^2 = 0.564$, $n = 28$, $P < 0.001$) and weighted elk crossings ($r = 0.772$, $r^2 = 0.596$, $n = 28$, $P < 0.001$).

Our calculations defined sections with high incidence of elk-vehicle collisions as those with at least 15 elk-vehicle collisions (mean = 12.3), and high crossing sections as those with at least 180 weighted crossings (mean = 135.1). All 6 of the sections with high incidence of elk-vehicle collisions (of 28 total) coincide with a bridged passage structure (underpass or bridge), and passage structures will occur on seven of the nine identified high crossing sections (Figure 9.7). Combined, 11 of the sections had high numbers of elk-vehicle collisions and crossings; 9 (81.8%) have an existing or planned passage structure (Figure 9.7).

9.3.6 Temporal relationships between elk-vehicle collision and crossing patterns

We detected monthly and seasonal differences in the frequency of both elk-vehicle collisions and highway crossings. Observed mean monthly collisions for all elk differed from expected ($\chi^2 = 34.0$, df = 11, $P < 0.001$), as did crossing frequencies for all elk ($\chi^2 = 220.8$, df = 11, $P < 0.001$; Figure 9.8). Elk-vehicle collisions that occurred during September-November accounted for 49% of all collisions (Figure 9.8); 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 elk-vehicle collisions ($P = 0.251$) and crossings ($P = 0.691$) did not differ from expected for cows, those involving bulls differed from expected (collisions $\chi^2 = 122.0$, df = 11, $P <$

0.001; crossing $\chi^2 = 114.6$, df = 11, $P < 0.001$; Figure 9.9); cow collisions and crossings were relatively consistent throughout the year. During November-April, only 18 crossings (7% of total) and 3 collisions (12%) involving bulls were recorded, with a subsequent increase from May-October (Figure 9.9). The proportion of elk crossings by month (as an expected proportion for elk-vehicle collisions) differed from the actual observed proportion of elk-vehicle collisions ($\chi^2 = 24.8$, df = 11, $P = 0.010$) and differed for both cows and bulls.

On an annual basis, the ratio of bull:cow elk-vehicle collisions (23.6:100) was less than half the mean bull:cow ratio (51.8:100) from annual surveys (2001-2005) conducted in GMU 22 and 23, and the surveyed ratio (expected) differed from the collision ratio (observed; $\chi^2 = 101.9$, df = 3, $P < 0.001$). However, considering only the period June-October which accounted for 85.7% of bull crossings and 84.0% of elk-vehicle collisions involving bulls. The bull:cow vehicle collision ratio (48.8:100) did not differ from the surveyed population bull:cow ratio ($P = 0.808$).

Table 9.9. Elk-vehicle collision (EVC) relationships between highway crossings and weighted crossings by 33 Global Positioning System-collared elk at various scales along State Route 260, 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
0.1 mi	208	0.396	0.156	<0.001	0.509	0.259	<0.001
0.3 mi	57	0.566	0.320	<0.001	0.700	0.489	<0.001
0.6 mi	28	0.688	0.474	<0.001	0.837	0.701	<0.001
1.0 mi	18	0.715	0.512	<0.001	0.833	0.693	<0.001
Section[b]	5	0.901	0.812	0.037	0.971	0.942	0.006

[a] Weighted elk crossings = ∑ (no. of elk crossings/segment × SDI)
[b] Average length of each highway section = 3.7 mi

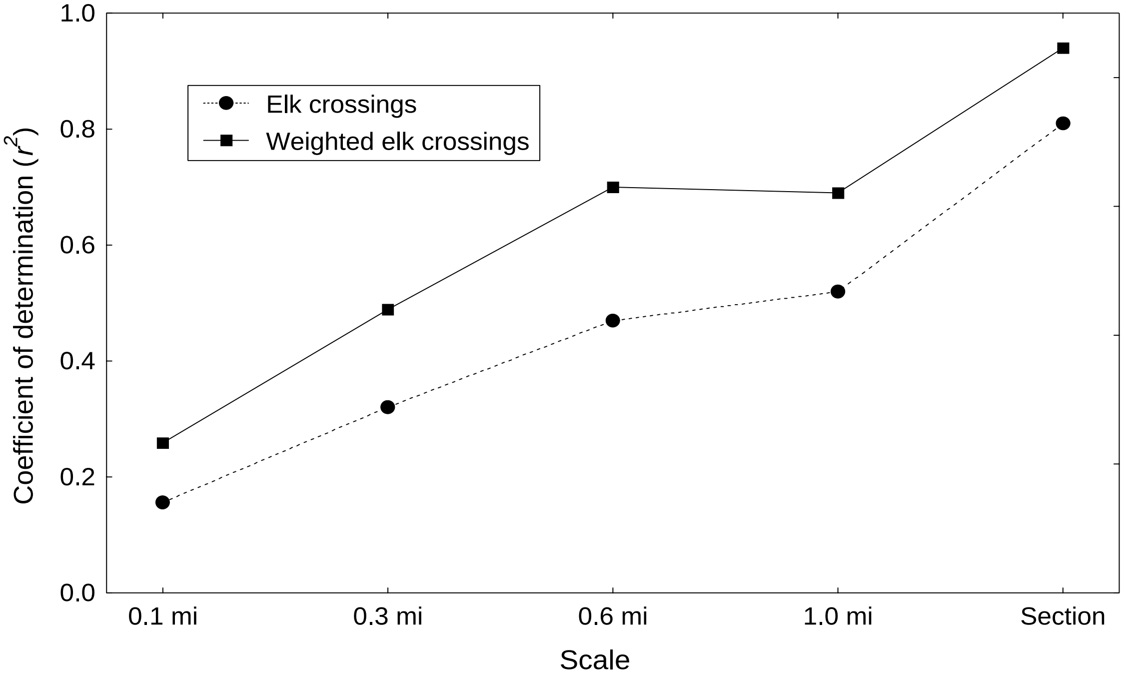

Figure 9.6. Coefficients of determination (r^2) for linear regression comparisons of elk-vehicle collisions to elk crossings and weighted elk crossings conducted at various scales along State Route 260.

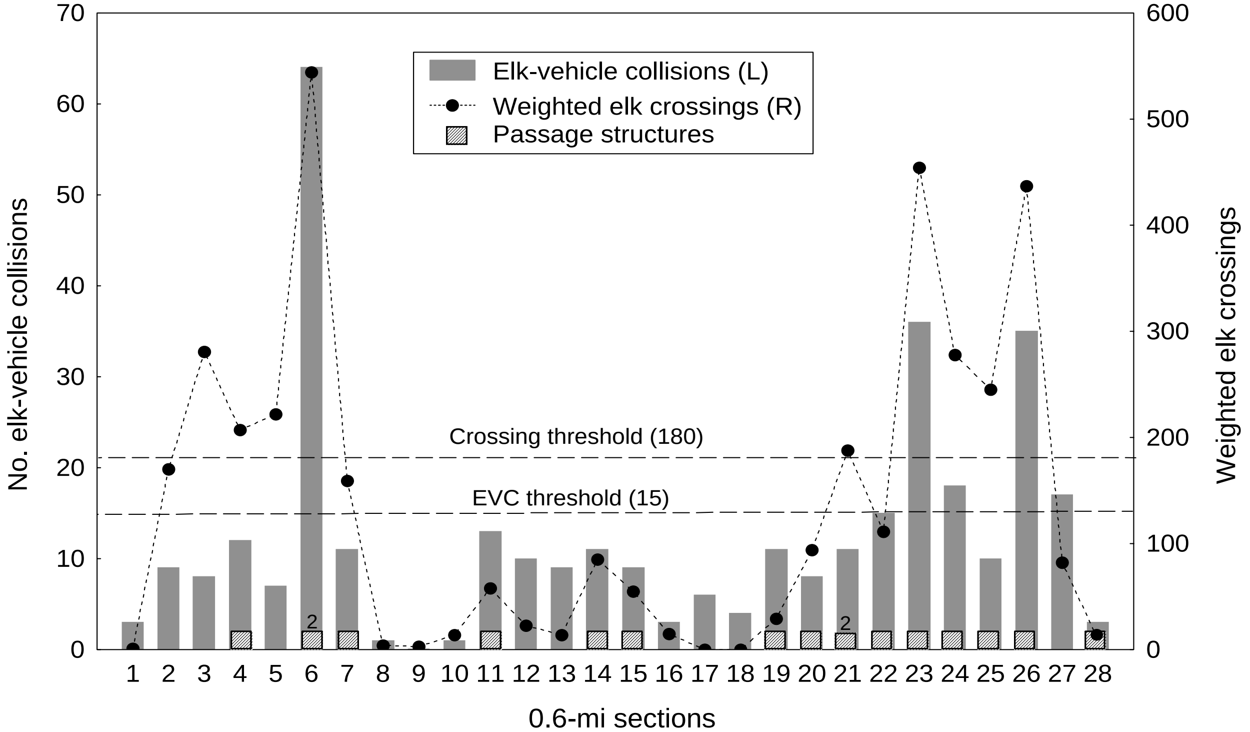

Figure 9.7. Frequency of elk-vehicle collisions and weighted elk crossings determined from 33 elk fitted with GPS collars 2002–2004, by 0.6-mi sections along State Route 260. Thresholds for high elk-vehicle collisions and crossings (Malo et al. 2004) denoted by dashed lines, and passage structures (underpasses and bridges) denoted by 0.6-mi segment in which they are located.

Recorded elk-vehicle collisions by day differed from expected ($\chi^2 = 22.0$, df = 6, $P < 0.001$), while elk crossings by day did not differ from expected ($P = 0.169$) unless we applied daily AADT factors to the expected crossings ($\chi^2 = 34.8$, df = 6, $P < 0.001$). However, the proportion of elk crossings by day (expected) did not differ from the proportion of elk-vehicle collisions ($P = 0.424$), even with daily AADT factors ($P = 0.520$). The greatest departures in daily elk-vehicle collisions above expected levels occurred on Monday (35% above expected) and Friday (19%), and the greatest departure below expected occurred on Wednesday (73% below expected; Figure 9.10). Using AADT daily factors to adjust for differential daily AADT, elk-vehicle collisions on Monday remained the highest of the week while Friday dropped 17% to below expected levels, and collisions on Sunday increased 12% (Figure 9.10).

Both the observed frequency of elk-vehicle collisions and elk highway crossings by 2-hour time interval differed from expected ($\chi^2 = 271.0$ 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 elk-vehicle collisions ($\chi^2 = 39.4$, df = 11, $P < 0.001$). The largest proportion of collisions (31%) occurred between 7:00 p.m. – 9:00 p.m., with nearly 60% of collisions reported between 5:00 p.m. – 11:00 a.m. (Figure 9.11).

The largest proportion of elk crossings occurred between 5:00 a.m. and 7:00 a.m. (18%); 83% of crossings were made at nighttime between 7:00 p.m. and 7:00 a.m. (Figure 9.11). A higher proportion of elk-vehicle collisions (59%) occurred relative to crossings (33%) in the evening hours (5:00 p.m.– 11:00 p.m.), while a lower proportion (19%) occurred during morning hours (3:00 a.m. – 9:00 a.m.) relative to crossings (34%). We found that 34% of elk-vehicle collisions occurred within a 1-hour absolute departure from sunrise or sunset, and 55.5% occurred within a 2-hour departure period (Figure 9.12). Similarly, 35% of deer collisions occurred within a 1-hour departure and 50% within two hours of sunrise or sunset (Figure 9.12).

9.4 DISCUSSION

The estimated proportion of wildlife killed by vehicles and recorded in wildlife-vehicle collision databases has ranged from 17% for deer (Forman et al. 2003), 25-35% for all wildlife species (Sielecki 2004), 50% for deer (Romin and Bissonette 1996*b*), to 80% for moose (Garrett and Conway 1999). The long-term ADOT database we used for our analyses included nearly 70% of all wildlife-vehicle collisions that were documented along SR 260 during 2001-2006. Though smaller and causing less property damage than elk, 68% of deer collisions were recorded in both databases.

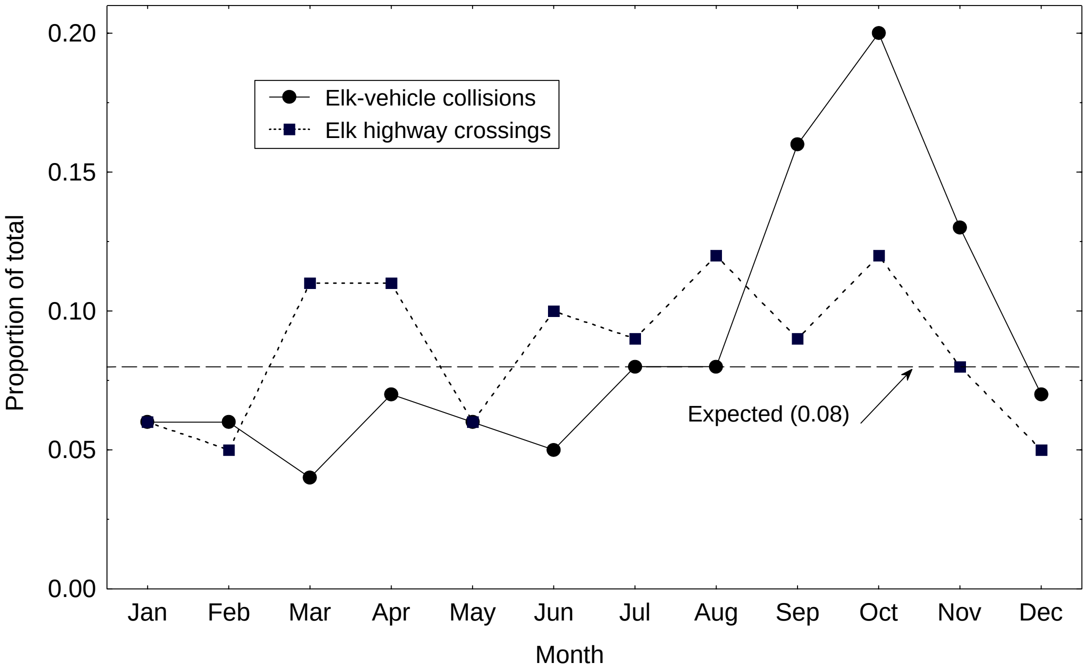

Figure 9.8. Proportions of elk-vehicle collisions (solid line) and elk highway crossings (dashed line) by month along State Route 260, Arizona. Observed elk-vehicle collisions ($\chi^2 = 34.0$, df = 11, $P < 0.001$) and elk crossings ($\chi^2 = 220.8$, df = 11, $P < 0.001$) differed from expected values.

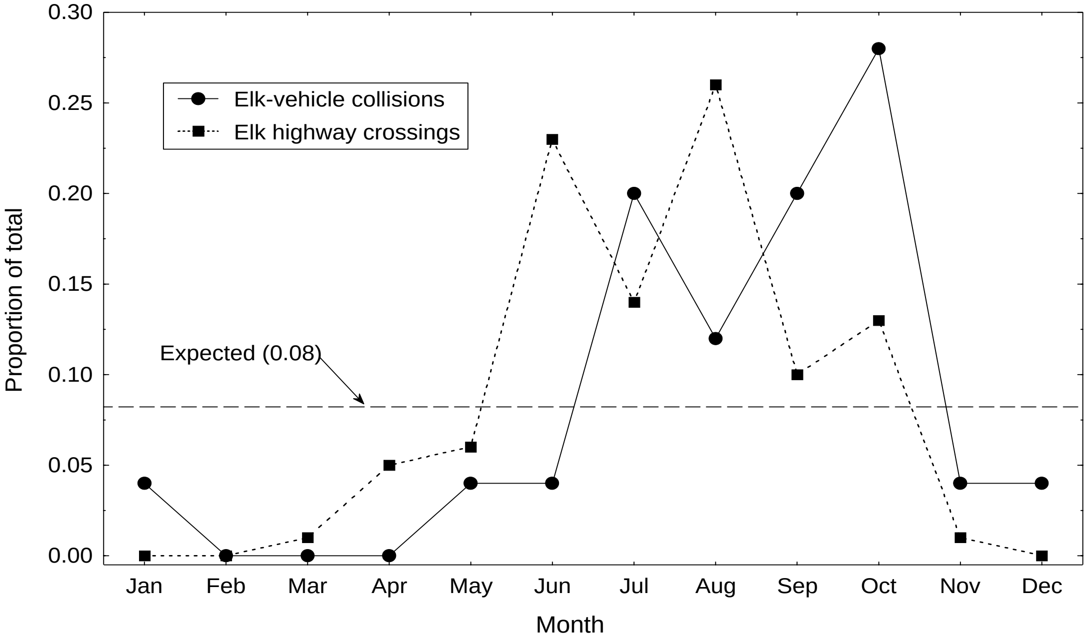

Figure 9.9. Proportions of elk-vehicle collisions (solid line) and elk highway crossings (dashed line) for bull elk by month along State Route 260, Arizona. Both observed collisions ($\chi^2 = 122.0$, df = 11, $P < 0.001$) and elk crossings ($\chi^2 = 114.6$, df = 11, $P < 0.001$) differed from expected values.

9.4.1 Elk-vehicle collision relationships to AADT and elk population estimates

We found that AADT and estimated elk population levels jointly influenced annual elk-vehicle collisions along SR 260; based on partial regression coefficients, AADT had a stronger influence, as reported by Seiler (2004).

Traffic volume has frequently been reported as a factor contributing to collisions with vehicles 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 wildlife-vehicle collisions (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 elk-vehicle collisions 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 elk-vehicle collisions ($r^2 = 0.75$) independent of traffic volume. Waller et al. (2005) developed a probabilistic measure of road mortality and theorized that highway lethality was related to both traffic volume and time spent on the roadway by crossing animals.

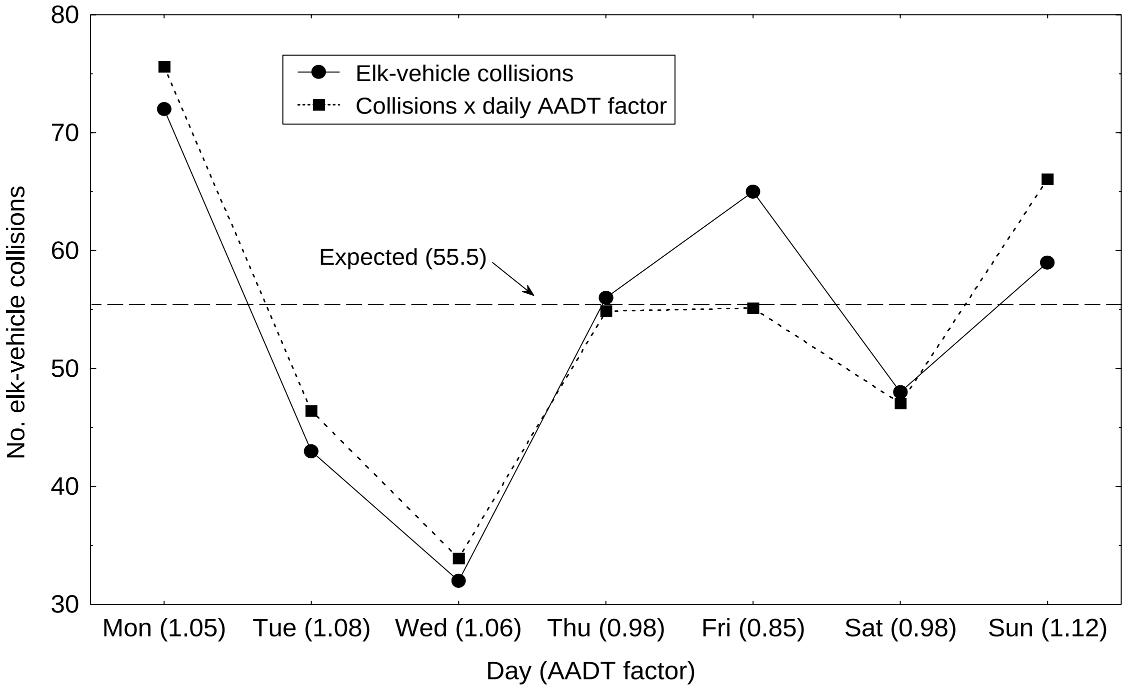

Figure 9.10. Elk-vehicle collision frequency by day and as corrected with daily AADT factors accounting for differential daily traffic volume. Both observed collisions ($\chi^2 = 22.0$, df = 6, $P < 0.001$) and AADT-corrected collisions ($\chi^2 = 20.7$, df = 6, $P < 0.001$) differed from expected values.

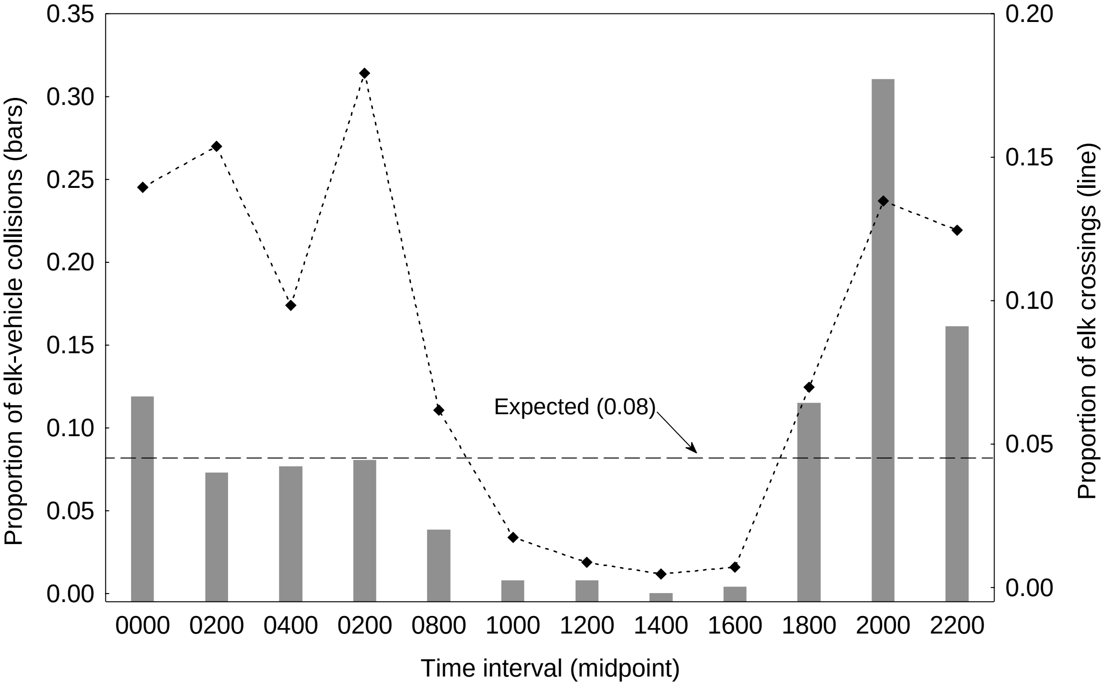

Figure 9.11. Proportions of elk-vehicle collisions (bars) and elk highway crossings (dashed line) by 2-hour time interval along State Route 260, Arizona. Both observed collisions ($\chi^2 = 271.0$, df = 11, $P < 0.001$) and elk crossings ($\chi^2 = 672.2$, df = 11, $P < 0.001$) differed from expected values.

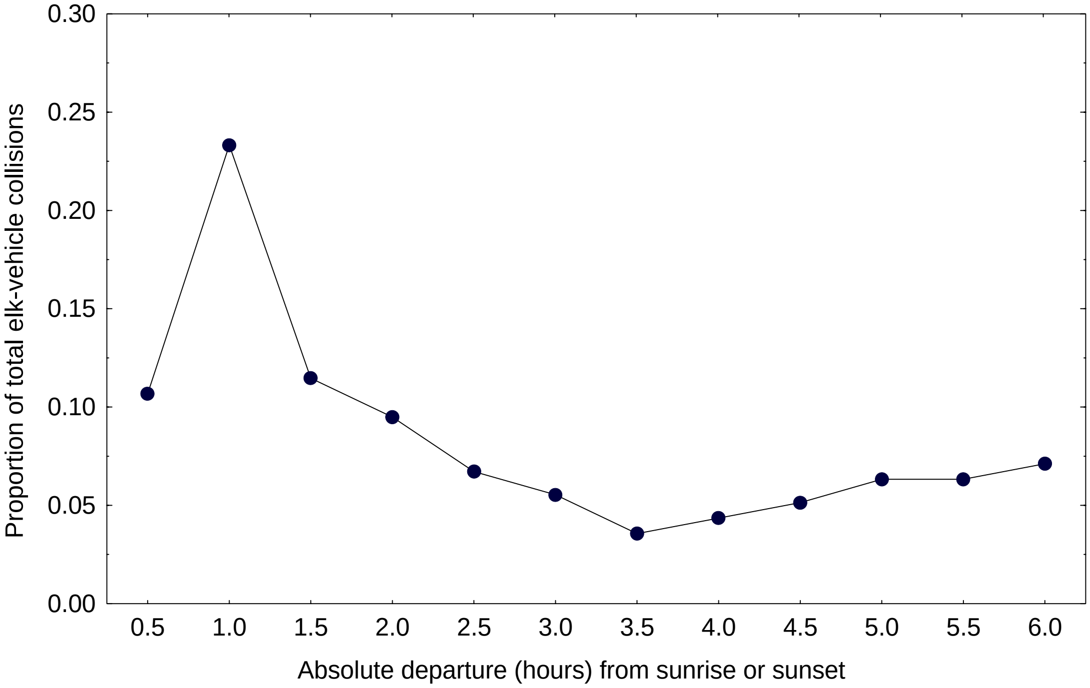

Figure 9.12. Absolute departure (by 0.5 hour increments) from sunrise or sunset for elk-vehicle collisions along State Route 260.

From 1994-2003, AADT increased an average of 17.8%/year; it is anticipated that AADT will continue to climb toward 10,000 vehicles/day in the near future. As our multiple regression modeling demonstrated, predicted elk-vehicle collisions showed a concomitant increase with AADT in the absence of measures to minimize them, such as underpasses and fencing. Given the general trend of increasing AADT, the fact that actual elk-vehicle collisions dropped below predicted amounts for the first year (2006) since the initial SR 260 section was reconstructed illustrates the benefit of measures to mitigate impact from both the reconstructed highway and increasing AADT. As other elements of the SR 260 reconstruction project come on line and realize their intended benefit, such as the newly opened Kohl's Ranch section and ongoing ungulate-proof fencing of the entire Preacher Canyon section, the degree to which these measures will yield benefits in reduced elk-vehicle collisions are anticipated to increase.

9.4.2 Comparison of elk-vehicle collisions by highway section and construction classes

Our mean elk-vehicle collision rate for all highway sections (1.6/mi/year in the long-term ADOT database, 2.5/mi/year in our database) exceeded those reported for Alberta (Gunson and Clevenger 2003) and British Columbia (Sielecki 2004), but was lower than the rate (2.6/mi/year) reported by Biggs et al. (2004) in New Mexico. The comparative rates for SR 260 sections validated the priority of reconstruction (Route 260-Payson to Heber EIS, ADOT Environmental Planning Section, Phoenix, AZ); Preacher Canyon section 1st (2.6/mi/year), Christopher Creek section 2nd (2.1/mi/year), and Kohl's Ranch section 3rd (1.1/mi/year). The two sections where reconstruction has not begun (Little Green Valley and Doubtful Canyon) had a combined elk-vehicle collision rate of 0.5/mi/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 the efficacy of measures to reduce wildlife-vehicle collisions 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. We have conducted such an assessment on two sections, Preacher Canyon (5 years of after reconstruction data) and Christopher Creek section (2 years). The recent completion of the Kohl's Ranch section will add a third section under BACI evaluation.

The incidence of elk-vehicle collisions on the Preacher Canyon section remained largely unchanged across all construction phases. Yet, given the 67% 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 elk-vehicle collisions at an even level in spite of increased traffic levels and while elk-vehicle collisions recorded on our two control sections in 2005–2006 increased dramatically. These measures have promoted elk permeability across SR 260, with more than 40% of weighted elk crossings for the Preacher Canyon section having occurred below grade at the three passage structures, even with limited fencing. With the unchanged elk-vehicle collision rate for this section, an enhancement grant was obtained to fence the remaining 2.7 mi of the section to reduce or eliminate elk-vehicle collisions, funneling more elk and other wildlife toward and through the Little Green Valley underpasses and the Preacher Canyon bridge.

The large increase in elk-vehicle collisions on the Christopher Creek section during construction between 2003 and 2004 reflected the opening of the highway to traffic before ungulate-proof fencing was completed, along with increased AADT and vehicular speed (Forman et al. 2003). While fencing that paralleled the highway was erected in spring 2004, fencing through the 7 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. In the six months between the Christopher Creek section opened to traffic and the fencing completed (December 2004), we documented 38 elk-vehicle collisions. In the two years since fencing was erected along 50% of the section an average of 11 elk-vehicle collisions were documented each year. Most collisions occurred along unfenced sections of the highway and at a 0.2-mi gap near Christopher Creek that was not fenced due to an access road (see Section 7.0 for further description of the role of fencing there). Fencing's utility in reducing wildlife-vehicle collisions 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 wildlife-vehicle collisions in the first year after fencing.

9.4.3 Cost-benefit of measures to reduce elk-vehicle collisions

With 2006 being the first year after three sections of SR 260 were completed and opened to traffic where actual elk-vehicle collisions were below the predicted amount. We believe that we're just now beginning to see the benefit of underpasses and fencing in effectively mitigating the impact of both highway reconstruction and increased AADT. Even with limited yet strategically placed fencing of less than 25% of the 17-mi stretch of SR 260 to date (see Dodd et al 2007*b* and Section 6.0), a 45% reduction in elk-vehicle collisions has been realized compared to 2004 levels before the Christopher Creek and Kohl's Ranch sections were fenced. Once the entire Preacher Canyon section is fenced by late-January 2007, a near 60% reduction from 2004 elk-vehicle collision levels will be realized. Further measures on the Christopher Creek section, and benefit from the recently completed Kohl's Ranch sections could increase this toward a 70% reduction from 2004 levels, preventing nearly 50 elk-vehicle collisions/year. With anticipated SR 260 AADT rise to 10,000 vehicles/day and a 70% reduction in elk-vehicle collisions, the benefit of measures to reduce elk-vehicle collisions will approach $1,000,000/year. With an estimated cost for 7 wildlife underpasses and fencing erected to date (including the Preacher Canyon section enhancement project) of approximately $15 million, the benefit associated with these measures will exceed their cost (in 2006 dollars) within 15 years.

9.4.4 Comparison of elk-vehicle collisions and elk highway crossings

GPS telemetry afforded us an unprecedented spatial and temporal assessment of elk highway crossing patterns and permeability (Dodd et al. 2007*b*; Section 6.0), and allowed us to compare crossing patterns to elk-vehicle collisions. With mean GPS fix accuracy to within ±33 ft, and with more than 85% of our fixes within 65 ft of known validation locations (Dodd et al. 2007*a*; Section 4), GPS telemetry constituted a sufficiently accurate tool to assess elk crossing patterns and address our study objectives.

9.4.4.1 Spatial relationships

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

Though intuitive, we confirmed the relationship between the frequency of elk highway crossings (and weighted elk crossings) and elk-vehicle collisions. 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. We also found that individual variation in crossing rates also influenced the likelihood of an elk being involved in a collision, with a relatively small proportion of elk that showed a high tolerance for vehicle traffic accounting for a large proportion of the vehicle-related mortality along SR 260.

Though our strongest relationship between weighted crossings and elk-vehicle collisions was found at the highway section scale, this scale provides limited management utility. The 0.6-mi scale was optimal as it afforded relatively high "power" ($r^2 > 0.7$) and was refined enough to be used to determine wildlife-vehicle collision and crossing patterns and to plan mitigation measures to address these collisions and permeability. At this scale, 9 of 11 (82%) high elk-vehicle collision or crossing segments have passage structures planned or already built. The relationship between crossings and collisions 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 elk-vehicle collisions and weighted crossings at the 0.1-mi scale probably reflected inaccuracy in both GPS elk crossing segment determination and wildlife-vehicle collision reporting error, as found by Gunson and Clevenger (2003; mean reporting error >0.12 mi).

9.4.4.2 Temporal relationships

We recorded a dramatic increase in the proportion of elk-vehicle collisions 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. For bulls, an even greater spike in collisions occurred from July-October, with peaks in

July and October. Gunson and Clevenger (2003) reported an increase in elk-vehicle collisions in fall attributable to increased elk numbers from calf recruitment, and Biggs et al. (2004) reported increased elk-vehicle collisions in fall and winter, with the collisions 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 elk-vehicle collisions probably reflected a combination of factors. First, the fall increase reflected an influx of migratory elk that moved from summer range atop the Mogollon Rim beginning in October (Brown 1990, 1994b); 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. This increase in overall elk numbers, in addition to calf recruitment (Gunson and Clevenger 2003) probably accounted for the fall peak in elk-vehicle collisions. Further, the onset of the breeding season in September and October coincided with peaks in the proportion of elk-vehicle collisions for bulls and all elk combined, both with the highest proportion of elk-vehicle collisions in October.

The influence of riparian-meadow habitats is reflected in seasonal fluctuations in elk-vehicle collisions and elk crossing patterns. Most apparent were the strong associations between collisions and crossings to the proximity to riparian-meadow habitats. The original alignment of SR 260 abutting several streams and large meadow areas 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 elk-vehicle collisions 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 collisions 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 collision and crossing patterns. While only 4% of the area within 0.6 mi of SR 260 was comprised of riparian-meadow habitats, 20% of all bull GPS fixes occurred in such habitats, including 46% of the fixes in August (Dodd et al. 2007*b*; Section 6). Cow elk also have high nutritional demands during lactation through the summer and fall (Nelson and Leege 1982); 38% of collisions 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 collisions at this time.

Gunson and Clevenger (2003) reported greater numbers of female elk-vehicle collisions, though the sex ratio was actually skewed toward bulls given their low bull:cow ratio. Romin and Bissonette (1996*b*) reported bias toward male deer in wildlife-vehicle collisions, as did Joyce and Mahoney (2001) for moose. Relying on the yearlong mean elk-vehicle collision sex ratio for SR 260 would lead us to conclude that elk-vehicle collisions disproportionately affect the female segment of the elk population relative to the surveyed ratio. However, in applying our GPS crossing data to address the elk-vehicle collision sex ratio only during the period when bulls crossed SR 260, elk-vehicle collisions occurred in proportion to the ratio of the surveyed population.

Gunson and Clevenger (2003) reported more elk-vehicle collisions on weekends (Friday-Sunday) than on 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 elk-vehicle collisions occurred on Monday. On Friday, the daily AADT-adjusted elk-vehicle collision rate was below expected in spite of the highest traffic volume, suggesting that elk responded to the 25% traffic volume increase between Wednesday (lowest collision incidence) and Friday. The incidence of collisions on Sunday exceeded the expected level especially when adjusted by daily AADT factors, and by Monday (23% below Friday traffic volume) collisions far exceeded the expected level. Thus, elk-vehicle collisions (and AADT daily factor-adjusted crossings) appeared to reflect a behavioral response of avoiding high traffic volume on Friday and Saturday, followed by elevated elk-vehicle collisions on Sunday and Monday despite lower traffic volume, as further reported by Gagnon (2006). 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. Friday and Saturday AADT levels often approached or exceed 10,000, leading to lower than expected elk-vehicle collisions and crossings reflective of behavioral adaptation by elk (Gagnon 2006). Surges in elk-vehicle collisions and crossings on Sunday and Monday probably reflected increased movements by elk following peak AADT days.

Haikonen and Summala (2001) reported that a large peak in wildlife-vehicle collisions, 46% of moose and 37% of white-tailed deer collisions, occurred within three hours after sunset tied to circadian rhythms associated with light. We found an even more dramatic peak in wildlife-vehicle collisions after sunset; 67% of elk collisions and 64% of deer collisions occurred within a 3-hour departure of sunset. Gunson and Clevenger (2003) and Biggs et al. (2004) noted similar evening peaks in elk-vehicle collisions, though the latter also noted a secondary peak in the morning tied to increased commuter traffic. Our morning elk-vehicle collisions remained below expected levels though a third of elk crossings occurred between 3:00 and 9:00 a.m.; SR 260 does not have morning traffic as reported by Biggs et al. (2004). Green and Bear (1990) found that 38-60% 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), Biggs et al. (2004), and we noted peak elk-vehicle collisions.

Our comparison of elk-vehicle collisions 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 elk-vehicle collision data as a surrogate measure of weighted crossings determined by costly GPS assessment. It also underscores the value of wildlife-vehicle collision 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 wildlife-vehicle collisions provides a means to assess the impact of highway construction on wildlife and to evaluate the effectiveness of measures to reduce these collisions and promote permeability. We found that aggregating elk-vehicle collision patterns to 0.6-mi segments provided a scale that optimized the strength of the relationship between elk-vehicle collisions and elk highway crossings and management utility.

Our temporal elk-vehicle collision 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 to use the underpasses (Clevenger and Waltho 2003).

Gaining an understanding of elk-vehicle collision patterns and identifying the relative collision potential associated with season, day, time, and relationships to traffic volume will provide highway planners insights to develop strategies for educating motorists of the risk of collisions with wildlife.

10.0 INFLUENCE OF ENVIRONMENTAL FACTORS ON ELK HIGHWAY CROSSINGS

10.1 INTRODUCTION

Vehicle collisions with ungulates are recognized as a serious problem throughout the world. Estimates of ungulates killed by vehicles are in the millions each year (Groot Bruinderink and Hazenbroek 1996, Romin and Bissonette 1996). The results from accidents with wildlife can include human injury, death, and property damage (Conover et al. 1995, Reed et al. 1982). Such risks to humans make it imperative to understand how specific environmental factors influence where ungulates cross highways and are involved in wildlife-vehicle collisions.

Many studies have used telemetry to measure ungulate habitat use in relation to roads (Ockenfels et al.1994, Johnson et al 2000, Rowland et al. 2000, Jones et al. 2002, Anderson et al. 2005), while others used distribution of ungulate pellets to infer where ungulates selected habitat in relation to roads (Perry and Overly 1976, Lyons 1979, Rost and Bailey 1979). Lesser used have been visual observation of ungulates using roadside habitats compared to random habitat types (Carbaugh et al. 1975) and identification of habitat selection via track pads located adjacent to roads (Barnum 2003). Johnson et al. (2000) determined from telemetry to that elk and deer avoided roads, but slope and aspect influenced where they approached roads. Ockenfels et al. (1994) found that collared pronghorn (*Antilocapra americana*) populations were isolated by roads and selected gentle slopes with grasses. Perry and Overly (1976) found that elk pellets were distributed away from roads and were more abundant in meadows on southwestern slopes. Lyons (1979) found that elk pellets were more abundant at roadsides with 75% canopy cover or higher. Roadside track beds showed that elk were more abundant with high woody cover.

Several studies have characterized and predicted potential ungulate-vehicle collision sites (Puglisi et al. 1974, Bashore et al. 1985, Finder et al. 1999, Hubbard et al. 2000, Neilsen et al. 2000, Biggs et al. 2004). Such studies have quantified site-specific variables in rural and urban areas over large scales with the majority of studies conducted in the upper-midwestern U.S. on eastern white-tailed deer. Puglisi et al. (1974) assessed deer collision sites in Pennsylvania, and found that location of fences adjacent to the highway and roadside vegetation were associated with collisions. Bashore et al. (1985) compared deer vehicle accident sites in Pennsylvania to random control points and found non-wooded habitat adjacent to the highway and in-line visibility of drivers increased the probability that a section of highway would have concentrated deer-vehicle accidents. According to Finder et al. (1999), when habitat parameters at deer-vehicle accident sites in Illinois were compared to random control sites, the accident sites had forest cover, presence of gullies and riparian corridors perpendicular to the highway and the control sites didn't. Hubbard et al. (2000) compared deer-vehicle accident sites on Iowa highways. Bridge frequency (elevated sections of the highway) was positively correlated with high deer collision sites. A Minnesota study compared 0.3-mi road segments with high and low incidence of deer-vehicle accidents. Accidents occurred within segments with few buildings and large land patches (Nielsen et al. 2003). Biggs et al. (2004) found that elk and deer accidents occurred on steep inclines where woody stems exceeded 6.5 ft in height.

Riparian habitat has been shown to be important for many terrestrial species (Patton 1997), providing important movement corridors and food resources (Meffe et al. 1997, Rosenberg et al. 1997). Several studies have shown that ungulate species preferentially utilize and move through riparian habitats (Compton et al. 1988, Larue et al. 1994, Williams et al. 2000). Because riparian habitat is an important resource for ungulate species, it should be included as a factor in research efforts to describe ungulate road crossing sites, particularly given the strong association between proximity to riparian-meadow habitats and the high incidence of elk highway crossings (Dodd et al. 2007*b* and Section 6) and elk-vehicle collision zones (Dodd et al. 2006). Riparian areas and drainages are also preferred travel corridors for elk (Skovlin 1982, Servheen et al. 2003).

Of the studies we reviewed addressing the factors associated with wildlife habitat use adjacent to highways or describing vehicle-collision patterns, most used five general variables: distance to roads or highways, road type, vegetation type, forage use, and slope. All but one considered vegetation, and slope was used as a factor in 60% of them. The significance of habitat factors varied among studies, and in most cases more than one variable proved influential. Four general themes emerged from the studies relative to the describing wildlife use in association with highways: 1) presence of grasslands, 2) topography, 3) cover, and 4) road avoidance. Grassland and pasture habitats were important factors for ungulates in half of the studies. Topographical factors including slope and aspect influenced elk and deer association to roads in 40% of the studies. Thirty percent of the reviewed studies indicated elk and deer used areas along roads with high canopy and/or hiding cover. Finally, 40% of the studies indicated that elk, deer, and pronghorn avoided roads at varying distances, and selected for habitats away from roads and highways.

Along State Route 260, both patterns of elk highway crossings determined from Global Positioning System (GPS) telemetry (*n* = 3,057; Dodd et al. 2007*b*, Section 6.0) and elk-vehicle collisions (*n* = 571; Dodd et al. 2006, Section 9.0) were not randomly distributed. Also, whereas most studies reported that ungulates avoided areas adjacent to roads and highways, Dodd et al. (2007*b*, Section 6.0) found that elk along SR 260 occurred in areas immediately adjacent to the highway at twice the expected frequency. Our objective was to employ Geographic Information Systems (GIS) analysis to determine environmental factors that influenced elk highway crossing patterns along SR 260, considering many of the variables reported as important in describing ungulate use patterns in association with highways in previous studies.

10.2 METHODS

This portion of our project was conducted along the entire 17-mi length of SR 260, along all five highway sections.

10.2.1 Determination of elk highway crossing patterns

We captured and instrumented elk with GPS collars at 10 sites along SR 260, and analyzed elk highway crossing patterns as detailed in Section 6.0 and in Dodd et al. (2007*b*) under our first phase of GPS telemetry research.

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 by SDI, as in Section 9.0 and Dodd et al. (2006). Weighted crossings were used to better reflect the crossing frequency, number of crossing elk, equity in distribution among crossing elk, and were more strongly associated with the distribution of elk-vehicle accidents along SR 260 than uncorrected crossings (Dodd et al. 2006, Section 9.0).

We divided SR 260 into 90 segments, each 0.2-mi in length, using ArcGIS® version 9.1. For each segment, we calculated weighted elk-crossing frequencies. From these 90 segments, we selected 20 each exhibiting the highest and lowest frequencies of weighted elk crossings:

- *High crossing segments* – weighted crossing frequency more than 40/segment (mean = 99.7 ±12.4).
- *Low crossing segments* – weighted crossing frequency less than 10/segment excluding those with no crossings (mean = 4.3 ±0.65).

10.2.2 Habitat assessment

We conducted our habitat assessment associated with the crossing sections using ArcGIS 9.1. We delineated landscape sampling blocks that extended out from each side of the highway 820 ft (by 1,050 ft along the segment: Figure 10.1). We incorporated the following environmental variables in our habitat analysis based on their reported importance to ungulate movement and behavior in relation to roads and highways:

- *Meadow distance* (Collins and Urness 1983; Jones and Hudson 2002, Dodd et al. 2007*b*; Section 6).
- *Water distance* (Finder et al. 1999; DelGuidice and Rodiek 1984)
- *Canopy cover* (Lyons 1979; Unsworth et al. 1998).
- *Slope* (Hershey and Leege 1982; Edge et al. 1987).
- *Aspect* (Edge and Marcum 1989).

We obtained Digital Raster Graphics (DRGs), or scanned maps, of the Diamond Point, Promontory Butte, and Woods Canyon 7.5-minute U.S. Geological Survey (USGS) topographic maps from Arizona Regional Image Archive (http://aria.arizona.edu/) to use as base maps for analysis. We added the following GIS layers to our base maps to conduct our analysis:

- SR 260 Highway shapefile.
- 0.2-mi highway segments shapefile
- Habitat sampling blocks shapefile.
- Water points shapefile.
- Meadow and riparian habitat locations shapefile.
- Ortho-rectified aerial photographs.

We defined meadows as tracts of open grasslands or wet meadows. We used ADOT aerial photographs shot in 2003 (1:2,000 scale) to determine the location and extent of all meadows within 0.6 mi of the SR 260 corridor. We ground verified all meadows and delineated them with a handheld GPS unit to create the meadow shapefile. We used the ArcGIS 9.1 distance tool to measure proximity between the starting vector point in the center of the 0.2-mi high or low frequency crossing segment and the end vector point at the nearest edge of the closest meadow.

We defined permanent water sources as water that was available to wildlife yearlong, persisting during the current prolonged drought conditions in central Arizona. Permanent water sources were identified from DRGs and local wildlife biologists. We validated all sources on the ground with a handheld GPS unit, and recorded water types (e.g., stream, spring, tank). We employed the ArcGIS 9.1 distance tool to measure proximity from the center vector point of each 0.2-mi segment and to the end vector point at the nearest edge of the closest permanent water source in meters.

We used previously-validated Forest Ecosystem Restoration Analysis GIS foundational data layers with 300- and 100-ft resolution raster files provided by the ForestERA Program; Northern Arizona University, Flagstaff, AZ, (Hampton et al. 2003) to obtain mean percent forest canopy cover, slope, and aspect for each of our 40 sampling blocks. We employed the GIS extension, Hawthorne's analysis tools (ArcGIS version 9) to clip rasters for each site and conduct zonal statistics to obtain the mean value for each sampling block for each of the three variables. Zonal analysis calculated a statistic of the variables for each zone, or in our case, each 0.2-mi segment.

10.2.3 Statistical analysis

All data were analyzed with the statistical package JMP version 5.1 (SAS Institute). We used a Classification and Regression Tree analysis (CART; Brieman et al. 1984) as an exploratory approach to determine the hierarchical order of importance for each variable measured for both high and low frequency elk highway crossing zones. We chose CART because it is conceptual, easily interpreted by highway managers, and an accepted method for highway safety studies (Stewart 1996). Each branch of the tree represents a split in the data that separates it into different categories based on the variable with the highest G^2 statistic at each split. If a parameter is continuous, it separates the means by examining the sums of squares due to the mean differences. If the parameter is categorical in nature, then the split is determined by the largest likelihood-ratio chi-square statistic. In addition to the CART, we calculated *t*-statistics to compare each habitat parameter individually between high and low crossing sites.

10.3 RESULTS

We compared the means of each variable for high and low frequency elk crossing sites. Differences in proximity to water and meadow each were significant ($P < 0.001$; Figure 10.2). Conversely, we did not find differences among high and low frequency highway crossing segments for percent canopy cover, slope, and aspect. The frequency of weighted elk crossings occurring in each highway segment was associated with the distance to water and meadow (Figure 10.3).

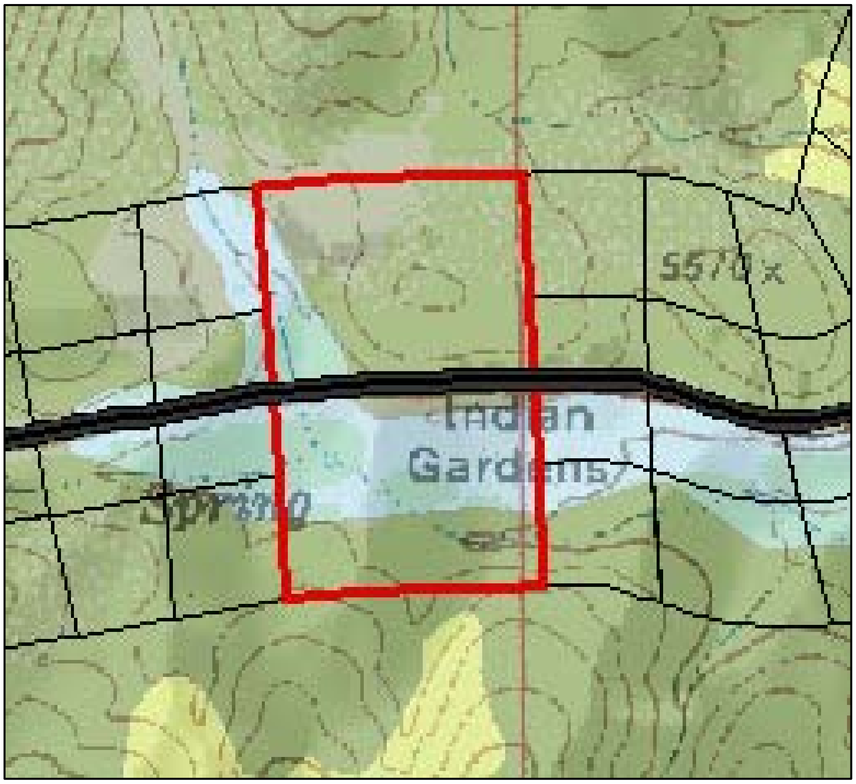

Figure 10.1. Schematic representation of the sampling block used to assess slope, aspect, and canopy cover at 0.2-mi high and low frequency elk highway crossing sites along State Route 260, Arizona. Each plot was 820 × 1,050 ft on each side of the highway. The blue-shaded area represents meadow habitat from which its size and distance to the center of the 0.2-mi highway segment were calculated.

Our CART model broke the GIS data into three hierarchical nodes or branches based on G^2-statistics for the five variables (Table 10.1; Figure 10.4). Two factors were represented in this model including proximity to water and proximity to meadow habitat. The first CART split, indicating the most important variable (Node 1; Figure 10.4), split the high and low frequency crossing segments by proximity to the nearest water source. All 20 high crossing sites (20) were located within 2,500 ft of a permanent water source, while half of the low crossing sites (10) were more than 2,500 ft from the nearest permanent water source.

The second CART split (Node 2; Figure 10.4) separated the crossing segments that were less than 2,500 ft from permanent water by distance to the nearest meadow habitat more than or less than 680 ft. At this node, we found that only high crossing sites (6) were located within the 2,500 ft of water and within 680 ft of the nearest meadow. The remaining sites (24) were more than 680 feet from the nearest meadow. The third node (Node 3; Figure 10.4) split the remaining crossing segments again by distance to the nearest meadow, at 3,100 ft. Eleven high crossing sites and five low crossing segments were less than 3,100 ft from the nearest meadow. Only three high- frequency elk crossing segments, and five low-frequency crossing segments were located more than 3,100 ft from meadow habitat.

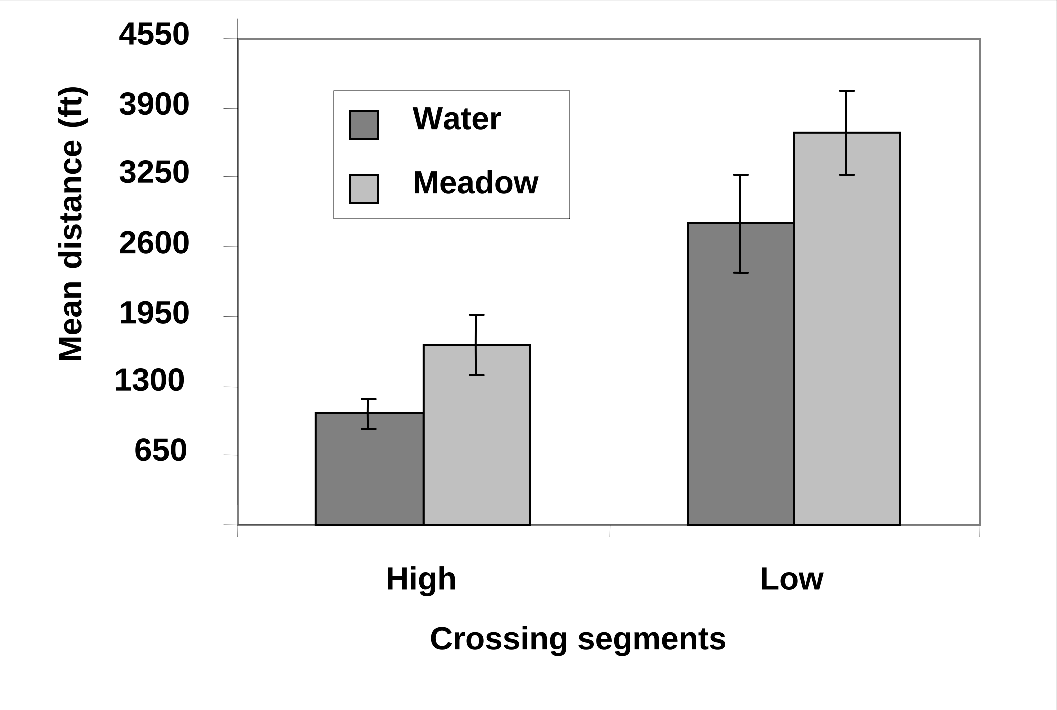

Figure 10.2. Mean distance to permanent water sources and meadow habitats (and SE bars) from the center fn 0.2-mi elk highway crossing segments, comparing high and low frequency crossing segments along State Route 260, Arizona.

Thus, 85% of the high-frequency elk crossing segments were where water was within 2,500 ft of SR 260 and the nearest meadow habitat was less than 3,100 ft from the highway (Figure 10.4). Conversely, 75% of our low-frequency crossing segments fell into two categories that differed from the high frequency crossing sites (Figure 10.2). Half of the low crossing segments were located more than 2,500 ft from water. Of those low frequency crossing segments that were within 2,500 ft of permanent water, none had meadow habitat within 3,100 ft of the segment.

10.4 DISCUSSION

Our study suggests that elk preferred to cross SR 260 near water and meadow habitats. Previous elk distribution studies showed elk preferred areas within 1,300–2,600 ft of permanent water sources (Bracken and Musser 1993, Delgiudice and Rodiek 1984, Mackie 1970, Nelson and Burnell 1975). When permanent water sources are limited, elk likely depend on moisture associated with succulent forage (Skolvin et al. 2002), which was present in the wet meadows adjacent to or near SR 260. Because our study was conducted in an arid environment, during a 10-year drought of which our GPS tracking period included two of the driest years on record, it is not surprising that elk exhibited dependence on available permanent water sources and forage in meadows.

Riparian and meadow habitats provide forage of highest nutritional quality, earlier in the growing season than adjacent forest habitats (Nelson and Leege 1982), and best meet the high protein demands of cows during latter stages of gestation and the mineral demands of bull antler growth (Bubenik 1982, Nelson and Leege 1982). As with our study, of 10 available habitat types, elk in Alberta used only grass-meadow habitat more than expected, selecting for highest quality foraging areas (Jones and Hudson 2002). A study conducted in central Arizona in a ponderosa pine forest adjacent to our study area indicated that the distribution of a combination of water and succulent grasses influenced elk distribution up to 1,300 ft (Delgiudice and Rodiek 1984). Riparian areas and drainages are also preferred travel lanes and corridors for elk (Skovlin 1982, Servheen et al. 2003). For these reasons, the SR 260 alignment adjacent to several stream courses and meadows has contributed to long-term wildlife-vehicle conflicts, including wildlife-vehicle accidents. This information supports Dodd et al (2006, 2007*b*; Section 6) in their findings that the incidence of elk-vehicle collisions and frequency of elk crossings along SR 260 were associated with proximity to riparian-meadow habitat.

Our highway crossings were calculated from linking two consecutive GPS fixes that occurred at two-hour intervals. Therefore, we assumed that the elk crossed SR 260 in a straight-line during the two-hour interval, though this is unlikely; they more likely crossed in a meandering manner. To help account for this potential bias, we used larger highway segments (0.2 mi) than those used by Dodd et al. (2006, 2007*b* and Section 6) to determine crossing frequency and measure habitat parameters

Wildlife-vehicle collisions are a serious problem: they cause tremendous property damage, reduce wildlife populations and their associated recreational value, and cause human injuries and deaths. Transportation and highway managers can reduce accidents with mitigation measures such as passage structures and ungulate-proof fencing. This study suggests that focusing these efforts where water is less than 2,500 ft and meadow less than 3,100 ft from SR 260 or other highways with similar habitats (e.g., Interstate-17 south of Flagstaff, AZ,) will yield the greatest benefit in resolving conflicts.

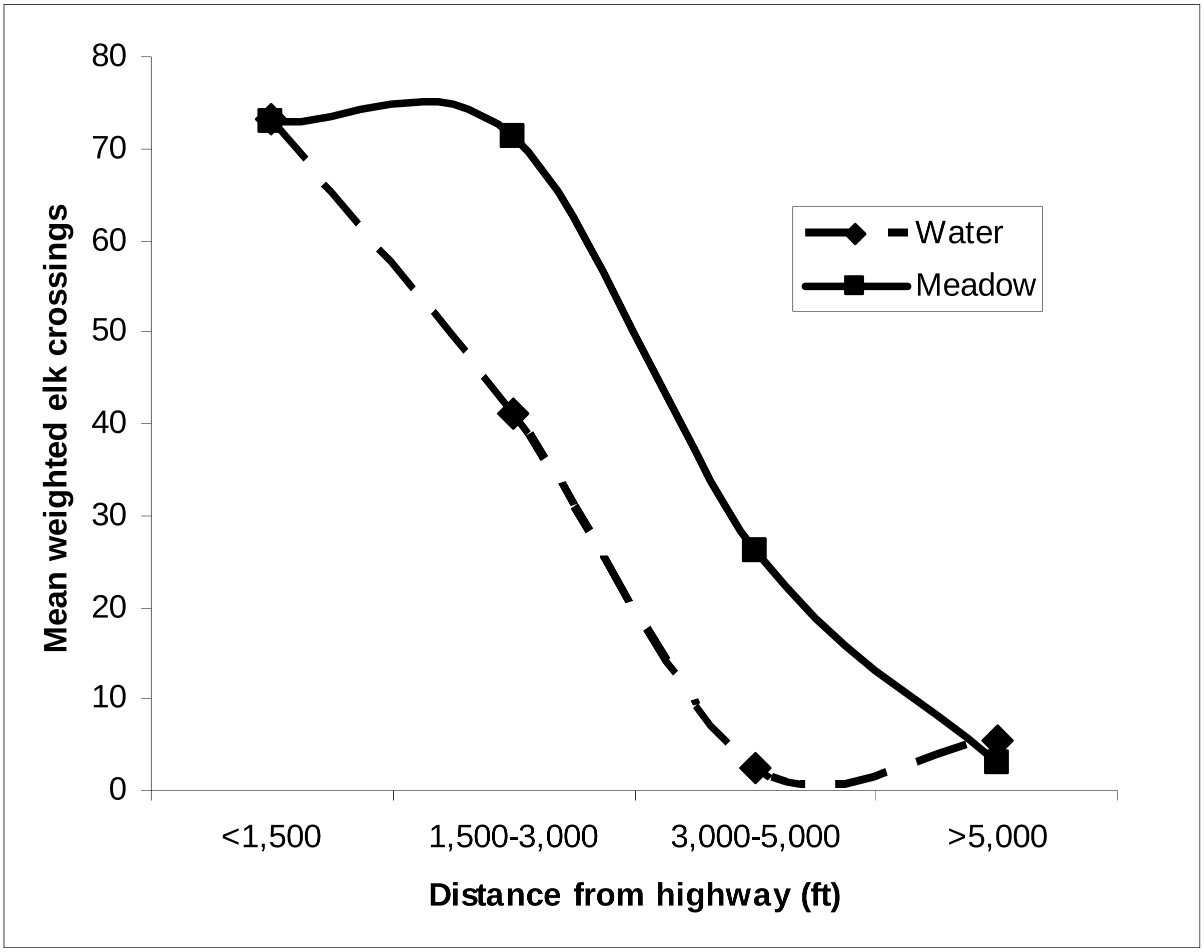

Figure 10.3. Relationships between the mean frequency of weighted elk crossings at 0.2-mi crossing segments along State Route 260, Arizona, and the distance to the nearest permanent water sources (dashed line) and meadow habitat (solid line).

Table 10.1. G^2-statistics associated with five variables used in the Classification and Regression Tree modeling of high and low frequency elk crossing segments along State Route 260, Arizona. Asterisks denote those variables with the highest G^2 levels upon which splits in the classification tree at three nodes were based (see Figure 10.4).

	Classification and Regression Tree G2 statistic		
Variable	Node 1 split	Node 2 split	Node 3 split
Proximity to water	17.3*	3.6	2.1
Proximity to meadow	15.1	5.6* (680 ft)	3.9* (3,100 ft)
Canopy closure	11.2	4.5	2.8
Aspect	0.4	0.6	1.0
Slope	1.7	4.5	2.8

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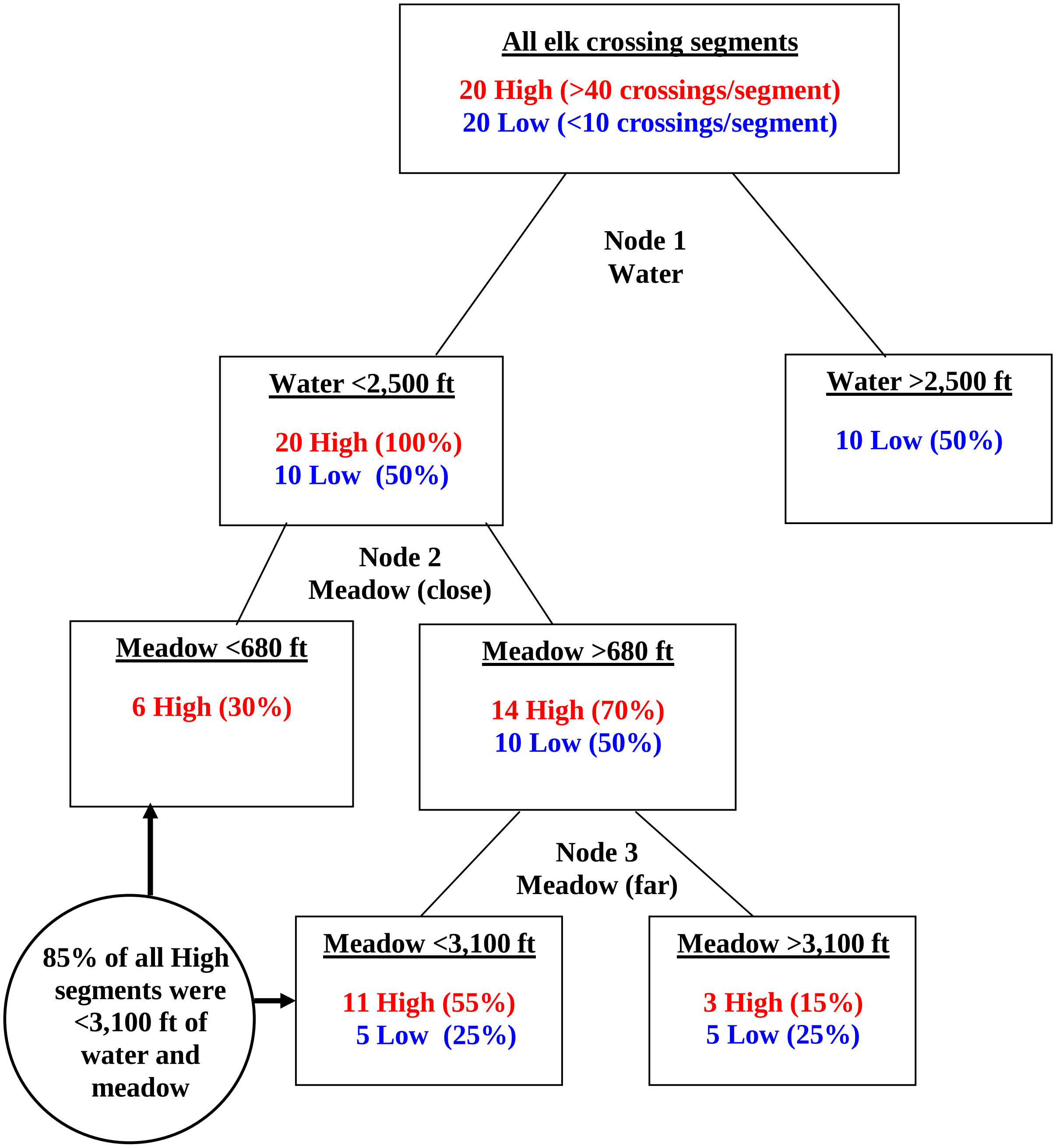


Figure 10.4. Classification and Regression Tree (CART) modeling decision tree for variables that described high and low frequency elk highway crossing sites, including proximity to nearest permanent water, proximity to meadow habitat less than or greater than 680 ft, and the proximity to meadow habitat less than or greater than 3,100 ft from 0.2-mi crossing segments along State Route 260, Arizona.

11.0 PRELIMINARY ASSESSMENT OF FACTORS INFLUENCING WILDLIFE USE OF HIGHWAY UNDERPASSES

11.1 INTRODUCTION

Whereas Section 3.0 of this report focused on wildlife use of the first two wildlife underpasses completed as part of the State Route 260 reconstruction, this section presents comparative results for all wildlife underpasses at which video surveillance monitoring has been conducted to date under all phases of our research. Since patterns of wildlife use of underpasses may change over time potentially affecting conclusions (Clevenger and Waltho 2003), coupled with the limited time that we have monitored wildlife use of the underpasses on the second reconstructed section of SR 260, the results presented here are considered preliminary. Though preliminary, they are nonetheless valuable due to the wider range of underpass locations, structural characteristics, and wildlife present at each underpass.

Structural characteristics and placement of underpasses have been reported to be important in describing their use by wildlife (Reed et al. 1975, 1979; Foster and Humphrey 1995; Clevenger and Waltho 2000; Ng et al. 2004). Prior studies modeled structural factors accounting for differences in wildlife use (Clevenger and Waltho 2000, 2005; Ng et al. 2004). Design and placement are important to underpass success, particularly if flawed design leads animals to avoid using it and continuing to cross the highway at grade, presenting a risk to motorists and animals.

In this portion of our project, we employed video surveillance to assess and compare wildlife use of five underpasses along SR 260. We examined factors influencing elk use of the underpasses by modeling underpass structure and temporal use factors.

11.2 STUDY AREA

This section of our report presents preliminary results of our video surveillance monitoring of two wildlife underpasses constructed on the Preacher Canyon section and three underpasses constructed on the Christopher Creek section (Figure 3.1); this monitoring was conducted under Phases I and II of our research project.

Reconstruction of the 3.0-mi Preacher Canyon section was completed in 2001, including construction of the underpasses at which we conducted our video surveillance. Both underpasses opened to the south into Little Green Valley, a relatively lush riparian-meadow foraging area contrasted by dense forest cover on the north side (Figures 4.1, 11.1, and 11.2). The two underpasses were situated less than 850 ft apart (Figure 4.1). Though both were of similar open-span bridge construction and length (135 ft), the below-span characteristics and dimensions were markedly different (Figures 11.1 and 11.2, Table 11.1). The East Little Green Valley underpass had more open, natural (vegetated earthen sides) characteristics (Figure 11.2) compared to the West Little Green

Valley underpass which had concrete, mechanically stabilized earth (MSE) walls (Figure 11.2). ADOT installed ungulate-proof fencing (8 ft) along 0.4 mi (13%) of the highway to funnel animals to the two underpasses (Figure 4.2).

The majority of heavy reconstruction on the 4.5-mi Christopher Creek section, including bridge and underpass construction was completed by May 2003, at which time wildlife could pass through the structures. 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 ungulate-proof fencing adjacent to 0.7 mi of the Christopher Creek section (22%), and was increased to 2.4 mi (49%) through the adaptive management process to address peak elk highway crossing zones determined by GPS telemetry (see Section 7.0).

On this section, four wildlife underpasses were constructed (along with three bridges over streams), three at which video surveillance was conducted (Table 11.1). The Pedestrian-Wildlife underpass (Figure 11.3) was constructed to accommodate wildlife as well as people traveling between the communities of Christopher Creek and Hunter Creek. It is an open-span bridge structure with a wide atrium between the bridges (Figure 11.3, Table 11.1). To the west, steep fill slopes and "elk rock" (see Section 8.0) funneled wildlife toward the underpass. To the east, approximately 0.6 mi of ungulate-proof fencing linked the Pedestrian-Wildlife underpass to the Hunter Creek bridge. The Wildlife 2 underpass also was an open-span bridge structure with a wide atrium (Figure 11.4, Table 11.1), though in this case the bridges were offset to accommodate an existing drainage (Figure 11.4). Ungulate-proof fencing extended in both directions from this underpass for more than 0.6 mi The Wildlife 3 underpass was our only single-bridge structure without an atrium (Figure 11.5). It was built close to the ADOT Colcord maintenance yard, with residences situated directly in front of the north approach to the underpass (Figure 11.5). On the west, the underpass was tied into the ADOT yard on the north with no fencing on the south side, while to the east, fencing extended 0.3 mi on both sides of SR 260.

Table 11.1. Structural characteristics associated with wildlife underpasses on State Route 260, Arizona, at which video camera surveillance was conducted from 2004–2006 to assess wildlife use, and the year in which underpass construction was completed and monitoring initiated.

	Year		Span	Height	Width	Length	Atrium
Underpass	Complete	Video	(ft)	(ft)	(ft)[a]	(ft)[b]	(ft)[c]
East LGV	2001	2002	135	22	32	175	36
West LGV	2001	2002	135	38	52	365	36
Pedestrian-wildlife	2003	2004	110	22	30	420	155
Wildlife 2	2003	2004	130	32	30	390	105
Wildlife 3	2003	2004	125	17	32	210	None

[a] Width = distance at the floor excluding fill slopes
[b] Length = distance for animals to fully negotiate passage structure, from mouth to mouth
[c] Atrium = width of opening between eastbound and westbound bridge spans

11.3 METHODS

11.3.1 Video surveillance systems

We used triggered four-camera video surveillance systems as described in Section 4.2 (and Dodd et al. 2007*a*, Gagnon et al. 2006) to examine the number and species of wildlife that used the five underpasses. These systems included two cameras that recorded animals approaching the underpasses from one side (approximately 130–150 ft from the mouth) and the other two cameras recording animals as they passed through (Figure 4.2). All camera systems were powered by 120-volt AC power, with the exception of the Pedestrian-Wildlife underpass ,which was solar powered (Figure 3.3). Our video camera systems on the Preacher Canyon section were installed in late 2002, yielding 3.5 years of monitoring data (Table 11.1). Camera systems on the Christopher Creek section were installed in early 2004, yielding 2.5 years of wildlife use data (Table 11.1).

11.3.2 Assessment of wildlife use of underpasses

For this preliminary analysis of our results for the five video-monitored underpasses, we limited our comparison to passage rates and did not include behavioral response as reported in Section 4.0 and Dodd et al. (2007*a*). Passage rates were determined from the proportion of animals crossing through to the proportion that approached each underpass. We considered an underpass approach to occur when animals crossed over the 3.5-ft

ROW fence approximately 130–150 ft from the underpasses and showed movement toward their mouths. Passage rates were only calculated from the side where the cameras were oriented (see Figure 4.2). As such, any wildlife approaching or crossing the underpasses from the opposite side were documented in the total recorded on videotape but were not incorporated into the passage rate.

11.3.3 Modeling factors influencing wildlife underpass use

We used a multiple logistic regression approach to select factors important in predicting a successful crossing through the underpasses by elk (Agresti 1996). These results were preliminary and limited to elk as they were the only species adequately represented across all underpass locations. Our binomial response variable was based on a successful crossing or non-crossing once an elk approached an underpass. We deemed factors important based on likelihood-ratio tests to test the significance of each selected factor given the other factors that were in the model (Agresti 1996).

We selected our factors based on what previous studies considered important in affecting elk movement associated with highways and their use of underpasses. We also felt that the time a structure was available to elk was a potentially important factor influencing underpass use. Although other wildlife species used the five underpasses, including white-tailed deer, mule deer, black bear, and mountain lion, we did not consider our sample sizes of other species adequately represented them across all underpasses. As such, we did not attempt a preliminary analysis of factors important to predicting probability of crossing for species other than elk; we will investigate factors important to these species at a later date after further monitoring.

In an attempt to minimize spurious results associated with our modeling, we limited our analysis to five total factors. We included factors that influenced elk movement in general, such as time of day and season to determine if the temporal movements of elk outweighed the importance of underpass structure. The five factors considered in our modeling included:

- *Underpass* (Clevenger et al 2000, 2005, Gagnon et al. 2006, Dodd et al. 2007*a*, Section 4) – this factor addressed differences in underpass structure and placement, as a categorical variable in the model.

- *Season* (Groot Bruinderink and Hazebroek 1996, Gunson and Clevenger 2003, Dodd et al. 2007*a*, chapter 4) - we selected seasons based on seasonal weather conditions and elk migration patterns:

    - Winter December–February.
    - Spring March–May.
    - Summer June–August.
    - Fall September–November.

- *Time of day* (Groot Bruinderink and Hazebroek 1996, Haikonen and Summala 2001, Dodd et al. 2006) - we partitioned days into four equally represented categories:

Morning	4:00 a.m. – 9:59 a.m.
Daytime	10:00 a.m. – 3:59 p.m..
Evening	4:00 p.m. – 9:59 p.m..
Nighttime	10:00 p.m. –3:59 a.m.

- *Months monitored* (Clevenger and Waltho 2003, Dodd et al. 2007*a*, Section 4) - the time since video monitoring was commenced was included in the model as a continuous variable.

- *Day of week* (Rost and Bailey 1979, Witmer and DeCelesta 1985, Gunson and Clevenger 2003, Gagnon 2006) - this factor served as a surrogate measure for traffic level, as SR 260 traffic levels were higher on weekends than weekdays (Gagnon 2006) .

Once we determined through multiple logistic regression the factors important to predicting the probability of elk using an underpass to cross, we further analyzed these factors graphically to assess associated patterns. We used a general linear model with a logit link to determine probabilities of a successful crossing for each of the factors selected, and further provide the odds ratios of a successful crossing for each of the scenarios selected as important by the logistic regression analysis. The equation used to calculate probabilities of successful underpass crossing for each significant factor is:

$$\text{Probability} = \left(\frac{\exp(\alpha + \beta x)}{1 + \exp(\alpha + \beta x)} \right)$$

This can be interpreted as the probability of a successful crossing under a given scenario versus that of a failure (1 – probability) once an elk approaches an underpass. Our α and β terms were provided by the model and represent the intercept and log odds respectively. Our comparative odds ratios for successful elk crossing at any two underpasses were calculated by dividing the odds of a successful crossing at one underpass by the odds for the other one being compared.

11.4 RESULTS

11.4.1 Wildlife underpass use and passage rates

We analyzed 1,100 hours of videotape recorded at the five underpasses from 2002–2006, and documented a total of 8,455 animals in 11 different species. Overall, 5,560 of these animals, or 65.8% crossed through the underpasses. Elk accounted for the majority of the wildlife documented at the underpasses (73.8%) while white-tailed deer and mule deer were 10.9% and 7.4% of the total, respectively. The highest overall passage rates for all wildlife were at the East Little Green Valley underpass (0.68 crossings/approach; Table 11.3), followed by the Pedestrian-Wildlife underpass (0.60; Table 11.4); the elk passage rate at both was 0.70 crossings/approach. The Wildlife 2 underpass had the lowest overall passage rate, 0.42 crossings/approach (Table 11.5) and an elk passage rate of only 0.30; only the Wildlife 3 underpass had a lower elk passage rate (0.10; Table 11.6).

In general, we noted an increasing degree of species diversity and evenness in the distribution recorded at the underpasses along a gradient from west to east, corresponding to an increase in elevation (see Section 2.0). Elk accounted for more than 90% of all animals recorded approaching and crossing the two Preacher Canyon section underpasses (East and West Little Green Valley underpasses, white-tailed deer were 6% of the total and mule deer less than 1%. At the three underpasses on the Christopher Creek section, elk accounted for 47% of all recorded animals, while white-tailed deer accounted for 19% and mule deer 15%. At the Pedestrian-Wildlife underpass, we documented the highest number of total white-tailed deer (485), number passing through an underpass (284), and passage rate (0.49 crossings/approach) of all monitored underpasses (Table 11.4). Conversely, our lowest white-tailed deer passage rate among the underpasses occurred at the two Little Green Valley underpasses, which averaged only 0.08 crossings/approach (Tables 11.2 and 11.3).

11.4.2 Modeling of factors influencing wildlife underpass use

Our logistic regression modeling found that four factors were important in predicting the probability of a successful crossing once elk approached the underpass (Table 11.7), including underpass structure, months monitored, season, and time of day. Day of the week, our surrogate factor for traffic volume did not have a significant influence on crossing probabilities at our below grade passage structures, consistent with Section 5.0 (Table 11.7).

Our underpass factor was the most important one identified in our modeling, suggesting that underpass structure and placement was of primary importance in predicting the probability of successful elk passage at the underpass (Table 11.7). The length of time an underpass was monitored was the second most important factor selected in our logistic regression modeling, followed closely by season. Time of day had the least influence of the four factors exhibiting a significant influence in predicting the probability of elk successfully crossing at our underpasses.

Figure 11.1. Aerial (left) and entry (right) views of the West Little Green Valley underpass looking north. Note how the underpass connects ponderosa pine forest to the meadow complex at Little Green Valley (left) and the concrete mechanically stabilized earth (MSE) walls (right).

Table 11.2. Number of animals by species recorded by video cameras at the West Little Green Valley underpass, number crossing through the underpass, and the passage rate (no. crossing/no. approaching). The underpass was completed in 2001 and video surveillance has been ongoing since 2002 (3.5 years).

Species	No. on videotape	No. crossing through underpass	Passage rate
Elk	1,365	879	0.62
White-tailed deer	95	5	0.08
Mule deer	9	0	0.00
Black bear	0	0	-
Mountain lion	0	0	-
Coyote	14	5	0.67
Grey fox	9	5	0.00
Raccoon	1	1	1.00
Other	22	14	0.83
Total	1,515	909	0.56

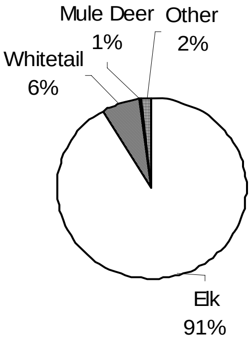


Figure 11.2. Aerial (left) and entry (right) views of the East Little Green Valley underpass looking north. Note how the underpass connects ponderosa pine forest to the meadow complex at Little Green Valley (left) and the 2:1 sloped earthen sides (right).

Table 11.3. Number of animals by species recorded with video surveillance at the East Little Green Valley underpass, number crossing through the underpass, and the passage rate (no. crossing/no. approaching). The underpass was completed in 2001 and video surveillance has been ongoing since 2002 (3.5 years). The graph (right) depicts the proportion of animals recorded on videotape by species.

Species	No. on videotape	No. crossing through underpass	Passage rate
Elk	3,336	2,604	0.70
White-tailed deer	205	21	0.07
Mule deer	2	0	-
Black bear	2	1	1.00
Mountain lion	5	1	-
Coyote	78	17	0.19
Grey fox	47	21	0.51
Raccoon	6	6	1.00
Other	12	10	0.83
Total	3,693	2,681	0.68

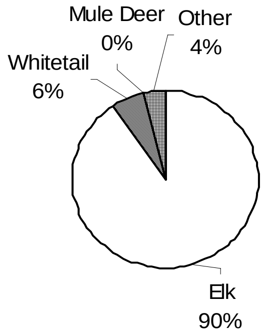


Figure 11.3. Aerial (left) and entry (right) views of the Pedestrian-Wildlife underpass looking north. Note how the underpass connects ponderosa pine forest on both sides of the highway and its wide atrium between bridges (left), and the high visibility through the underpass from the approaches (right).

Table 11.4. Number of animals by species recorded with video surveillance at the Pedestrian-Wildlife underpass, number crossing through the underpass, and the passage rate (no. crossing/no. approaching). The underpass was completed in 2003 and video surveillance has been ongoing since 2004 (2.5 years). The graph (right) depicts the proportion of animals recorded on videotape by species.

Species	No. on videotape	No. crossing through underpass	Passage rate
Elk	663	433	0.70
White-tailed deer	485	284	0.49
Mule deer	59	30	0.42
Black bear	3	1	0.50
Mountain lion	1	0	-
Coyote	11	4	0.20
Grey fox	60	34	0.71
Raccoon	143	48	0.59
Other	35	3	0.67
Total	1,430	837	0.60

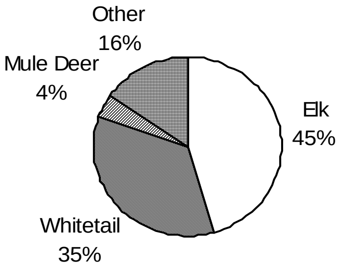


Figure 11.4. Aerial (left) and entry (right) views of the Wildlife 2 underpass looking north. Note how the underpass connects ponderosa pine forest on both sides of the highway and its wide atrium between bridges (left), as well as the relatively poor visibility through the underpass from the floor (right) associated with the offset nature of the bridge placement (left).

Table 11.5. Number of animals by species recorded with video surveillance at the Wildlife 2 underpass, number crossing through the underpass, and the passage rate (no. crossing/no. approaching). The underpass was completed in 2003 and video surveillance has been ongoing since 2004 (2.5 years). The graph (right) depicts the proportion of animals recorded on videotape by species.

Species	No. on videotape	No. crossing through underpass	Passage rate
Elk	827	411	0.30
White-tailed deer	81	42	0.31
Mule deer	488	407	0.64
Black bear	0	0	-
Mountain lion	4	2	0.00
Coyote	10	6	0.50
Grey fox	51	31	0.55
Raccoon	16	7	0.31
Other	13	8	1.00
Total	1,490	914	0.42

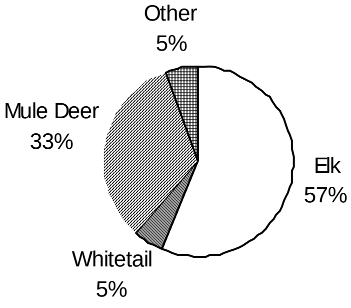
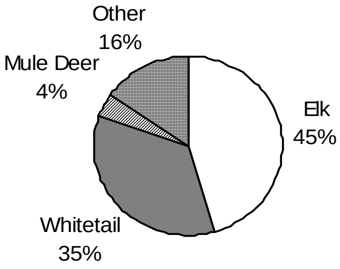


Figure 11.5. Aerial (left) and entry (right) views of the Wildlife 3 underpass looking north. Note that this is the only single-bridge underpass without an atrium that we monitored. Also note its proximity to the ADOT Colcord maintenance yard and residences (left).

Table 11.6. Number of animals by species recorded with video surveillance at the Wildlife 3 underpass, number crossing through the underpass, and the passage rate (no. crossing/no. approaching). The underpass was completed in 2003 and video surveillance has been ongoing since 2004 (2.5 years). The graph (right) depicts the proportion of animals recorded on videotape by species.

Species	No. on videotape	No. crossing through underpass	Passage rate
Elk	78	12	0.10
White-tailed deer	63	47	0.50
Mule deer	68	51	0.53
Black bear	0	0	-
Mountain lion	0	0	-
Coyote	0	0	-
Grey fox	1	1	-
Raccoon	98	97	0.31
Other	18	11	0.90
Total	327	219	0.45



11.4.3 Influence of underpass structure and placement

With underpass design determined to be our most important factor influencing the probability of a successful elk crossing at the five underpasses, we believe this factor reflects variation among underpasses relative to structural design, placement, or both. However, it is important to recognize that our interpretation is tempered by the limited replications of underpass type and placement. We had only one instance afforded at Little Green Valley where placement was controlled for two of our underpasses (East and West) which were situated literally side-by-side (Figure 4.1) allowing us to evaluate the influence of structure alone (Dodd et al. 2007*a*, Section 4.0). Given the substantial differences in design and placement among our five underpasses, we nonetheless believe our results provide valuable insights into the influence of design and placement.

The probability of a successful elk crossing among underpasses ranged from 0.77 at the East Little Green Valley underpass to only 0.09 at the Wildlife 3 underpass; our Wildlife 2 underpass was intermediate to these probabilities at 0.34 (Table 11.8). In making pairwise comparisons of the odds of successful elk crossings between the five underpasses, we found that the odds of elk crossing at the East Little Green Valley underpass were higher than all others, ranging from 32.5:1 greater odds of a successful elk crossing here versus at the Wildlife 3 underpass, to 5.2:1 greater odds for the Pedestrian-Wildlife underpass (Table 11.9). The Wildlife 3 underpass, conversely, had odds for a successful underpass crossing lower than all other underpasses (Table 11.9).

Table 11.7. Likelihood ratio test results for five factors modeled by multiple logistic regression analysis for successful elk crossing at five underpasses along State Route 260, Arizona, assessed by video camera surveillance conducted 2004-2005, including logistic regression chi-square (χ^2) statistic, probability, and degrees of freedom (DF). Asterisks correspond to those factors that had a significant influence on elk underpass crossing probabilities.

Model factor	DF	Logistic regression χ^2	χ^2 Probability
Underpass	4	110.1	$P < 0.001$*
Months monitored	1	38.3	$P < 0.001$*
Season	3	26.8	$P < 0.001$*
Time of day	3	11.4	$P = 0.010$*
Day of week	1	0.1	$P = 0.970$ NS

Table 11.8. Probability of a successful elk crossing at five wildlife underpasses along State Route 260, Arizona, determined by logistic regression.

Probability of successful elk crossing by underpass				
East LGV	West LGV	Pedestrian-Wildlife	Wildlife 2	Wildlife 3
0.77	0.49	0.64	0.34	0.09

Table 11.9. Comparison of odds of a successful crossing at 5 wildlife underpasses along SR 260 in central Arizona. The number on the left side of each ratio is associated with the structures listed in column one.

	Comparative odds of successful elk underpass crossing by underpass				
Underpass	East	West	Wildlife 2	Pedestrian-Wildlife	Wildlife 3
East		9.6:1	18.1:1	5.2:1	32.5:1
West	1:9.6		2.4:1	1:3.6	15.0:1
Wildlife 2	1:18.1	1:2.4		1:3.1	6.2:1
Pedestrian-Wildlife	1:5.2	3.6:1	3.1:1		18.1:1
Wildlife 3	1:32.5	1:5.2	1:6.2	1:18.1	

11.4.4 Influence of video surveillance monitoring length

As the second most important factor influencing the probability of a successful elk crossing at our five underpasses, the length of time that they were monitored relates to the "learning curve" associated with elk habituation. In the first year of monitoring, the probability of a successful elk crossing at the underpasses was 0.52. The probability increased 36% to 0.71 in the second year, and leveled off over the next 2 years (Table 11.10). In comparing the passage rate for elk at the underpasses over three years of video monitoring, the mean passage rate at four of the five underpasses showed a dramatic increase from the first year to the second, with a slower increase in the third (Figure 11.6). We noted a concomitant decrease in the number of elk groups that approached at the underpasses over three years (Figure 11.6) reflecting a reduction in the number of failed approaches, thus accounting for the increase in passage rates. The mean monthly elk passage rates over 46 months (Figure 11.7) also reflect a general increase over time with continued monitoring.

Table 11.10. Probability of a successful elk crossing by year at five wildlife underpasses along State Route 260, Arizona, determined by logistic regression.

Probability of successful elk crossing by year			
Year 1	Year 2	Year 3	Year 4
0.52	0.71	0.69	0.69

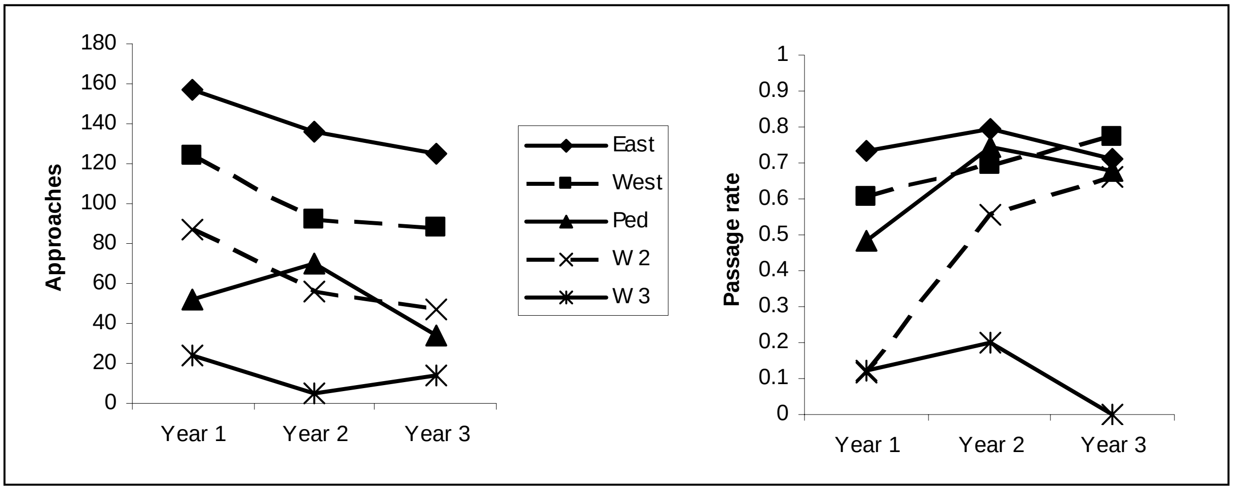


Figure 11.6. Number of elk groups that approached the five wildlife underpasses (left) and mean elk passage rate for the underpasses (right) over three years of video surveillance monitoring, State Route 260, Arizona. In key, East = East Little Green Valley, West = West Little Green Valley, Ped = Pedestrian-Wildlife, W 2 = Wildlife 2, and W 3 = Wildlife 3 underpasses.

11.4.5 Influence of season

We found the highest probability of an elk successfully crossing through the five underpasses was during summer (0.71), with the lowest probability occurring during fall (0.59; Table 11.11). The comparative odds of a successful elk crossing in fall were lower than those for the other three seasons, ranging from 1:1.4 (spring) to 1:1.7 (summer). We recorded the highest number of elk underpass crossings during spring during the period of forage green-up in meadows adjacent to SR 260, coupled with the migration of elk to a summer range atop the Mogollon Rim (Figure 11.8). Our mean elk passage rate for the five underpasses was at its highest in spring and summer (higher than 0.65), but dropped to its lowest (0.55) in fall and winter when non-habituated migratory elk are present (Figure 11.8). Monthly elk passage rates over 46 months show a recurring pattern of declines during the fall-winter months to below 0.40 followed by recovery in passage rate in spring-summer to higher than 0.80 (Figure 11.7)

Table 11.11. Probability of a successful elk crossing by season at five wildlife underpasses along State Route 260, Arizona, USA, determined by logistic regression

Probability of successful elk crossing by season			
Winter	Spring	Summer	Fall
0.64	0.67	0.71	0.59

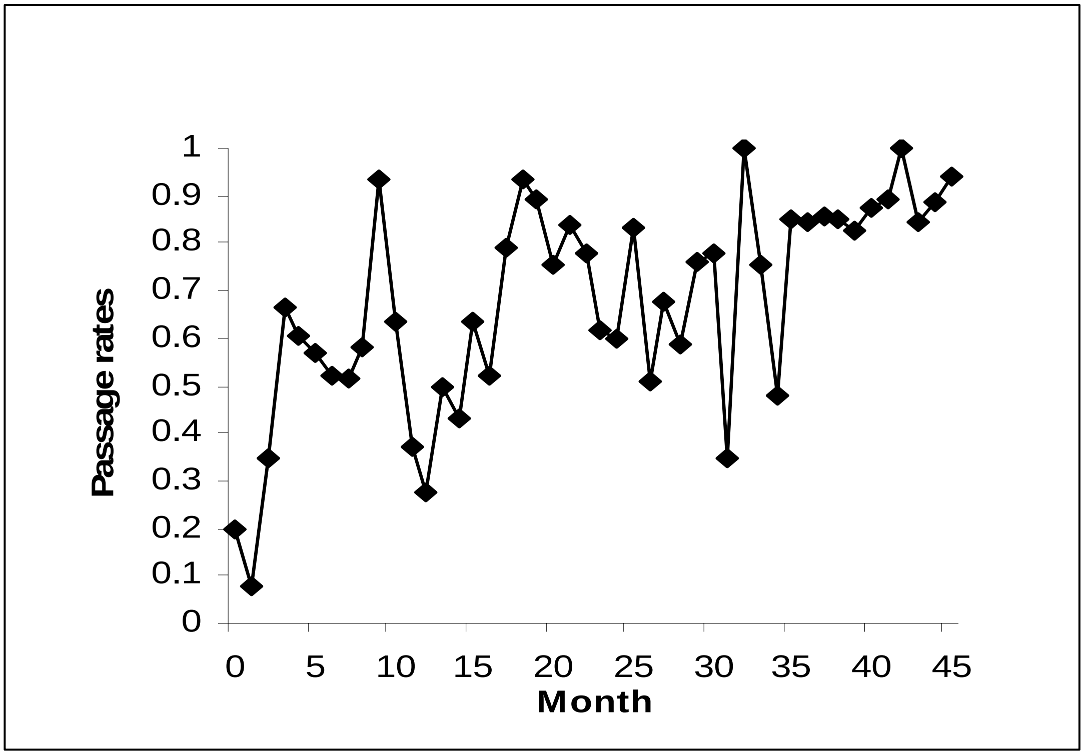


Figure 11.7. Mean monthly elk passage rates for five underpasses at which video surveillance monitoring has been ongoing for four years (2002–2006) along State Route 260, Arizona.

11.4.6 Influence of time of day

Our logistic regression modeling found that the probability of a successful elk underpass crossing was highest (0.73) in the evening hours and was higher than that for other times of the day (Table 11.12). The comparative odds of a successful elk crossing during the evening hours were higher than all other times, ranging from 4.0:1 (night) to 2.2:1 (daytime). The odds of successful daytime crossings were lower than all other times.

Table 11.12. Probability of a successful elk crossing by time class at five wildlife underpasses along State Route 260, Arizona, determined by logistic regression.

Probability of successful elk crossing by time			
Morning	Day	Evening	Night
0.55	0.44	0.73	0.58

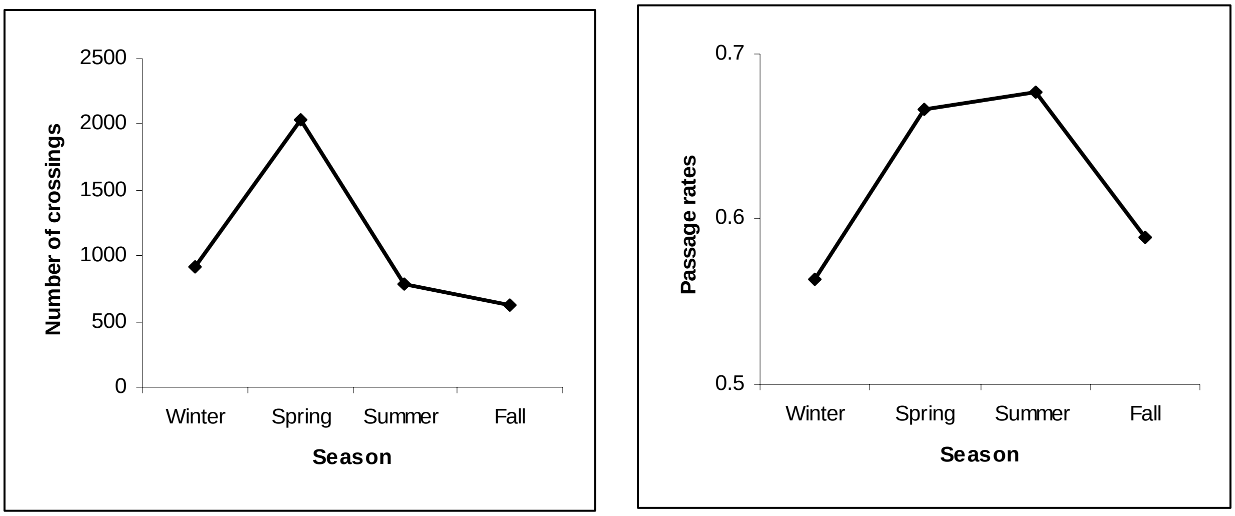


Figure 11.8. Number of elk underpass crossings (left) and mean passage rate (right) at five underpasses along State Route 260, Arizona, determined from video surveillance 2002–2006.

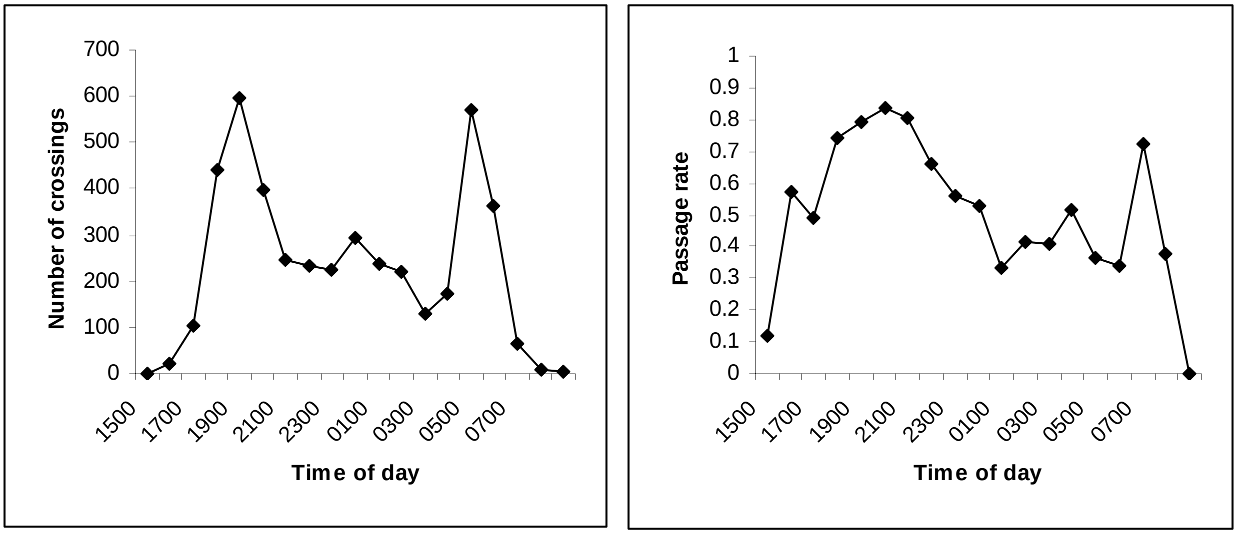


Figure 11.9. Number of elk crossings (left) and passage rate (right) by time of day for five underpasses along State Route 260, Arizona, determined from video surveillance 2002–2006.

The number of elk crossing through SR 260 underpasses had a marked bi-modal pattern relative to the time of day of the crossings, with one peak in the evening (7:00 – 9:00 p.m.) and another in the morning (6:00 –8:00 a.m.; Figure 11.9). Peak passage rate occurred during a period extending from :7:00 - 11:00 p.m., with a spike in the morning at 8:00 a.m.

11.5 DISCUSSION

As reported in Section 4.0 and by Dodd et al (2007*a*), video surveillance constituted a valuable means to assess and compare wildlife use at the five underpasses particularly when using passage rates and probability of underpass use as metrics for comparison. With nearly two-thirds of the 8,455 animals recorded on tape to date having crossed through the underpasses, their collective efficacy in reducing at-grade crossings should be apparent. Though our experimental design was limited in replications of similar types and placements of underpasses, as available to Clevenger and Waltho (2000, 2005) and Ng et al. (2004) in their modeling of structural factors accounting for differences in wildlife use, our results nonetheless provide compelling insights relative to the influence of underpass design and placement on wildlife use. Such attributes have been reported as crucial to achieving successful use of underpasses by wildlife (Reed et al. 1975; Beier and Loe 1992; Foster and Humphrey 1995; Clevenger and Waltho 2000, 2005; Forman et al. 2003; Dodd et al. 2007*a* and Section 4; Gagnon et al. 2006). Further monitoring of these five underpasses, as well as a sixth recently completed on the Kohl's Ranch section will provide additional insights into the importance of underpass structural characteristics.

Though the East Little Green Valley and Pedestrian-Wildlife underpass had comparable elk passage rates (0.70), the probability of a successful crossing was considerably higher at the East underpass, as were the comparative odds for a successful crossing (5.2:1). The success of this underpass reflects its structural attributes including high openness ratio and 2:1 earthen sloped sides, coupled with its proximity to a preferred elk foraging area and placement in an established drainage travel corridor (Section 4.0, Dodd et al 2007*a*; Figure 11.2), not to mention a longer period of time since construction. And yet, just 850 feet away and opening into the same meadow complex, the West Little Green Valley underpass had a lower elk passage rate and probability of successful crossing (0.47 versus 0.77) and comparative odds of a successful crossing (1:9.6). As discussed in Section 4.0, the East underpass openness ratio was over two times higher than that of the West. The greater length associated with the West underpass, where elk had to traverse more than 2 times the length of the east underpass to cross, largely accounted for the difference in openness ratios, and certainly played a large role in the observed difference in elk use and response to the two underpasses (Dodd et al. 2007*a* and Section 4). In addition to underpass length, we believe the concrete walls at our West underpass (Figure 11.1) had a substantial influence on the lower probability of elk crossing compared to the East underpass. In analyzing West underpass videotapes, we frequently observed animals standing at the mouth or just inside the underpass looking upward from side to side. Though we did not document predator-prey interactions at either underpass as described by Little et al (2002), elk nonetheless appeared hypervigilant of predators potentially lurking atop the concrete walls of the West (see Section 4.0, Dodd et al. 2007*a*). Little et al. (2002) recommended designing underpasses for prey species (e.g., elk, deer) to minimize predation risk with short, wide, and high passages. Though several structural factors contributed to the lower elk passage rate and probability of use for the West underpass, we believe that the ledge effect, the unnatural feel associated with its concrete walls, and its greater length accounted for the differences in elk response.

Our comparison of the Pedestrian-Wildlife and Wildlife 2 underpasses on the Christopher Creek section provide insights into the importance of underpass bridge placement. Though both underpasses are of similar open span bridge construction with wide atria, they differed dramatically in the alignment of their bridges (Figures 11.3 and 11.4), which was reflected in their respective elk passage rates (0.70 versus 0.34) and probabilities of successful elk crossing (0.64 versus 0.34). The Pedestrian-Wildlife underpass bridges were constructed in line allowing approaching animals to see completely through the structure (Figure 11.3). Conversely, the Wildlife 2 underpass bridges were offset in their placement along the existing drainage alignment, even though the integrity of the drainage was disrupted by funneling flows into large culverts below the underpasses. When approaching the underpasses at floor level, through views were fully obstructed by fill slopes due to the offset bridge placement (Figure 11.4). During our first year of monitoring the two underpasses, the passage rate for the offset Wildlife 2 underpass was 0.12 crossings/approach compared to 0.48 at the Pedestrian-Wildlife underpass. Since ungulate-proof fencing was erected in late-2004, the passage rates for the two underpasses have converged, pointing to both the role of fencing in promoting wildlife use of underpasses (see Section 7.0) and the ability of elk to habituate to underpasses (Clevenger and Waltho 2003).

Our Wildlife 3 underpass was the only single-bridge structure constructed and monitored along SR 260 (Figure 11.5); this underpass had the lowest elk passage rate (0.10 crossings/approach) and odds of a successful crossing (0.09) among the underpasses we monitored. We believe that it’s placement in proximity to the ADOT Colcord maintenance yard and residences (with associated human and pet-related disturbance) overrode the influence of its structural design characteristics in our assessment of wildlife use. Clevenger and Waltho (2000) found that human use and presence at wildlife underpasses, especially at underpasses soon after being constructed, adversely affected wildlife use.

We noted dramatic differences in the passage rates of white-tailed deer among our underpasses. At the two underpasses in the Preacher Canyon section (East and West) adjacent to the Little Green Valley meadow complex, we recorded over 300 deer at the underpasses with a low combined passage rate of 0.07 crossings/approach. At the Pedestrian-Wildlife and Wildlife 2 underpasses, where 566 white-tailed deer were recorded, over 57% of the deer have passed through the underpasses; passage rates averaged 0.49 and 0.31 crossings/approach, respectively. Rather than underpass structural design characteristics accounting for these differences, we believe that inherent habitat selection on the part of this secretive subspecies of white-tailed deer, coupled with avoidance of open grassland areas (Ockenfels et al. 1991) accounted for the difference in passage rates. The two Little Green Valley underpasses connected ponderosa pine forest cover on the north to the meadow complex to the south (Figures 11.1 and 11.2), whereas the two Christopher Creek section underpasses linked forest cover on both sides of SR 260 (Figures 11.3 and 11.4); the wide atria associated with these two underpasses compared to the Little Green Valley underpass may also have contributed to relatively high passage rates for white-tailed deer.

The reconstruction of SR 260 has evolved into an adaptive management project where the results of our monitoring of underpass effectiveness have been applied elsewhere along the highway. Original plans for the Indian Gardens underpass on the Kohl's Ranch section entailed more than 40,000 ft^2 of concrete walls for soil stabilization, which was considered inconsistent with achieving high wildlife use given the wildlife response noted at the East Little Green Valley underpass. Based on our results, ADOT eliminated the concrete walls and increased floor width from 50 to 100 ft to enhance wildlife use of the Indian Gardens underpass (Figure 11.10). We have been monitoring wildlife use of this underpass since March 2006, and in the first six months since it was completed, 241 animals were recorded passing through the structure with a combined passage rate of 0.63 crossings/approach for all species. The elk passage rate of 0.81 crossings/approach far exceeds the rate measured at any of the other underpasses, especially so soon after construction, and is testimony to the benefit of changes made reflective of the adaptive management process.

The amount of time that our underpass was monitored had a significant influence on elk passage rates. Clevenger and Waltho (2003) found relatively rapid acceptance of new underpasses by elk, achieving peak use within two years, and Dodd et al. (2007*a*, Section 4) reported a high degree of elk habitation to underpasses within 18 months, especially during summer. On the Christopher Creek section, ungulate-proof fencing erected in December 2004 served to steepen this learning curve and increase use of otherwise relatively marginal underpasses (see Section 7.0).

Figure 11.10. The Indian Gardens wildlife underpass on the Kohl's Ranch section (looking north from the east-bound lanes bridge), State Route 260, Arizona, where nearly all originally-planned concrete walls were removed upon construction, widening the underpass floor for wildlife passage, retaining native vegetation, and improving openness. The wall on the lower left corner of the photo is associated with a wildlife escape ramp (note the gap in the fencing).

Dodd et al. (2007*a* and Section 4) reported on the recurring pattern of lower elk passage rates in the winter season at the two Preacher Canyon section underpass, which they believed coincided with the time when migratory elk travel from above the Mogollon Rim to wintering areas adjacent to SR 260 (Brown 1990); these non-resident elk diluted the influence of habituated resident elk. We noted the same seasonal pattern for all underpasses along SR 260. Migratory elk appear to not have the same propensity for habituation to underpasses as resident elk since they typically winter south of the SR 260 corridor and are not exposed to the underpasses on a regular basis. This seasonal decline in passage rates associated with migrating elk has the potential to limit the achievement of consistent, high, yearlong underpass elk passage rates. We believe ungulate-proof fencing may be the key to maximizing underpass use by funneling a greater proportion of animals to underpasses and limiting options for elk to cross the highway elsewhere (Ng et al. 2004). Such fencing has proven effective in funneling animals to underpasses and in reducing wildlife-vehicle collisions (Clevenger et al. 2001*b*, Section 7.0). Along SR 260, the overall distribution of passage structures (1 structure/1.0 mi) limits wildlife crossings at grade without creating a continuous barrier severely limiting permeability.

Our logistic regression modeling found time of day to influence elk passage rate and probability of successful underpass crossing. Dodd et al. (2007*a* and Section 4) reported the highest passage rate and probability occurred during evening hours (4:00–10:00 p.m.). They also reported a bimodal crossing pattern that coincided with elk-vehicle collisions along SR 260, of which 67% occurred within a 3-hour departure from sunrise/sunset, similar to Haikonen and Summala (2001) and Gunson and Clevenger (2003).

The fact that day of week, our categorical surrogate variable for traffic volume was not found to influence the elk underpass passage rate was itself significant, indirectly suggesting that traffic volume does not influence wildlife underpass use. This corroborates the findings reported in Gagnon (2006) and Gagnon et al. (2007*a*) that traffic volume had little impact of elk passage below grade at wildlife underpasses (see Section 5.0). Conversely, traffic volume did influence elk crossing patterns and distribution at highway grade (Gagnon 2006, Gagnon et al. 2007*b*; Section 8.0), helping illuminate the reason that ungulate-proof fencing that funneled elk to underpasses actually resulted in an increase in highway permeability (Section 7.0).

12.0 CONCLUSIONS AND RECOMMENDATIONS

We have integrated and synthesized the findings from all of our volumes that report the findings of our research along State Route 260 to develop the following conclusions and recommendations. The basis for several of our conclusions was derived from multiple volumes, and in some instances, similar conclusions were derived from independent aspects of our research using different methodologies. Though our conclusions were specific to SR 260, recommendations are more generic in nature and thus are applicable to other highways and locales. Recommendations are highlighted using the symbol ☞.

12.1 HIGHWAY PLANNING AND MONITORING

The combined application of phased construction, adaptive management, and effective monitoring and evaluation of measures to reduce wildlife-vehicle collisions (WVC) and promote permeability were instrumental to jointly achieving transportation and ecological objectives.

☞We recommend a phased, adaptive management approach to highway construction and monitoring, when and where possible.

☞ADOT and other agencies should make a concerted effort to collect and archive wildlife-vehicle collision data throughout Arizona, utilizing the standardized interagency collision report form. Such an effort could provide valuable information for future highway planning and design.

☞Effective monitoring should be incorporated and funded as part of all construction projects, which will further add to the body of knowledge on effective wildlife collision mitigations and contribute to the "toolbox" of potential measures for application on highways.

12.2 ROLE OF RIPARIAN AND MEADOW HABITATS

Along SR 260, the presence of lush riparian/streamside and wet meadow habitats constituted the "engine" that drove conflicts between the highway and wildlife, particularly during the extended 10+-year drought being experienced in central Arizona. We found that wildlife-vehicle collisions, especially those involving elk, and elk highway crossing patterns determined by GPS telemetry were closely associated with proximity to riparian-meadow habitats.

☞Highway construction should avoid limited, valuable riparian and wet meadow habitats where possible, including other similarly important wildlife habitats elsewhere in the state associated with other wildlife species.

12.3 WILDLIFE UNDERPASSES

Structural design characteristics and placement of underpasses are important in maximizing their efficacy in promoting wildlife passage. We found underpass structural characteristics to be the most important factor in determining the probability of achieving successful crossings by wildlife.

As reported in other studies, underpass openness is important to achieving high probability of successful crossings by wildlife. Our data suggest that underpass length, the distance that animals must travel through an underpass, is an especially important factor in maximizing their efficacy.

☞Where possible, length should be minimized in designing wildlife underpasses. Atria between underpass bridge spans contribute to openness, especially for underpasses exhibiting longer lengths.

☞The application of concrete walls in wildlife underpasses should be avoided.

☞Offset underpass bridges should be avoided and used only where the bridges span natural stream courses and drainages; where offset bridges are necessary, the use of fill material that can limit animal visibility should be minimized.

☞Wildlife underpass placement should avoid concentrated areas of human disturbance or places where humans congregate outside daytime hours.

12.4 INFLUENCE OF TRAFFIC VOLUME ON WILDLIFE

We found that traffic volume influenced elk crossing patterns and distribution at highway grade. With increasing traffic levels, we found reduced probability of successful elk highway crossings at grade, crossings occurred later in the evening when volume levels abated, and elk moved away from the highway as volumes increased. Unsuccessful attempts to cross SR 260, or "repels" typically coincided with high traffic volume.

At our monitored wildlife underpasses, traffic volume on SR 260 overhead generally did not have an effect on elk approaching and successfully crossing through the underpasses. This finding was of paramount importance to understanding the efficacy of underpasses in promoting wildlife permeability.

We did note limited impact of traffic volume on elk at underpasses during very high AADT levels (>9,000 vehicles/day); increasing traffic volumes on SR 260 could have increased impact in the future, to the degree that measures may be necessary to mitigate the impact of vehicle noise associated with high AADT (e.g., rubberized asphalt on bridges and approaches, sound walls, etc.). At very high traffic levels, such measures could create "quiet zones" that attract crossing animals.

12.5 WILDLIFE PERMEABILITY RELATIONSHIPS

Fencing in conjunction with passage structures promoted wildlife permeability as animals were funneled toward underpasses and bridges where they crossed below grade with minimal impact from traffic passing above.

☞Fencing should be considered an integral component of wildlife mitigation measures to promote permeability in concert with effective passage structures, and should extend outward from passages a distance sufficient to funnel animals and prevent at-grade crossings. Short wing fences (e.g., 250-300 ft) extending out from passage structures will not promote permeability or highway safety. Fencing alone without effective passage structures will not promote permeability.

12.6 HIGHWAY SAFETY/WILDLIFE-VEHICLE COLLISIONS

With only a modest increase in AADT, we estimated that the annual benefit from reduced elk-vehicle collisions at nearly $1 million/year. The benefit derived from wildlife underpasses, ungulate-proof fencing, and other measures along SR 260 will exceed their cost in approximately 15 years.

12.7 ROLE OF UNGULATE-PROOF FENCING

In addition to playing an instrumental role in promoting permeability, ungulate-proof fencing was crucial to achieving effective use of underpasses, especially those not located in proximity to meadow habitats. Without fencing, elk and deer continued to cross SR 260 at grade immediately adjacent to underpasses. With fencing, elk and deer passage rates and probabilities of successful crossing through underpasses increased dramatically.

☞In the absence of GPS crossing data, wildlife-vehicle collision data can serve as a useful surrogate from which to plan the extent of ungulate-proof fencing. In determining the extent of fencing, attention must be given to terminating fencing at logical sites such as an underpass or bridge, large cut slopes, or in deep canyons so as to avoid potential for concentrated animal crossings at an “end run.”

We found that the benefit of ungulate-proof fencing in promoting wildlife use of underpasses was particularly important for relatively marginal passage structures. We achieved greater improvement in the probability of successful wildlife crossings with fencing for underpasses that received limited wildlife use before fencing. This finding has potential implications for retrofitting of structures not specifically designed for wildlife passage that might be considered marginal; fencing has the potential to funnel and “force” animals to these structures.

Our application of steep cut and fill slopes as an alternative to ungulate-proof fencing was not effective in deterring at grade highway crossings, as such slopes apparently did not constitute a barrier to elk passage.

Though beneficial in reducing wildlife-vehicle collisions, maximizing underpass use by wildlife, and promoting permeability, fencing nonetheless requires constant maintenance and attention to maintain its integrity and limit potential for liability.

☞Ungulate-proof fencing along SR 260 should be checked and maintained at frequent intervals to ensure its long-term integrity and continued benefit in promoting a safe highway.

12.8 FUTURE STATE ROUTE 260 RECONSTRUCTION SECTIONS

Compared to the first three reconstructed sections, the Little Green Valley and Doubtful Canyon sections exhibited relatively few wildlife-vehicle collisions or elk GPS crossings (with the exception of the R-C Scout Ranch area of the latter section where riparian-meadow habitat is located in proximity to the highway).

☞On the Little Green Valley section, fencing should be erected from the western abutments of the single planned wildlife underpass westward to the existing Preacher Canyon section fencing that terminates at the eastern end of the Little Green Valley meadow complex. This will eliminate most wildlife-vehicle collisions that occur beyond the end of the Preacher Canyon section fence, funneling all animals that encounter the fence to an underpass.

On the Doubtful Canyon section, three wildlife underpasses are planned.

☞Priority should be given to ungulate-proof fencing associated with the underpasses in the R-C Scout Ranch area where considerable wildlife-vehicle collisions and elk GPS highway crossings have been documented. The extent of this fencing must be such that potential “end runs” are avoided.

☞At the other two planned underpasses near Doubtful Canyon, fencing should be erected along the limited distance between them to link them together and funnel all animals that encounter the fence to an underpass. The terminal ends of the fence extending from the far side of each underpass should extend into deep canyons or terminate at large cut slopes where possible to avoid “end runs.”

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