Research Article

Effects of Traffic on Elk Use of Wildlife Underpasses in Arizona

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ABSTRACT We used video surveillance at 4 wildlife underpasses along 27 km of Arizona State Route 260, USA, to monitor elk (*Cervus elaphus*) responses to traffic volume and traffic type during underpass use. Passage rates at the highest traffic category (>10–27 vehicles/min) were not lower than passage rates when no vehicles were present, whereas passage rates at low, intermittent traffic volume (>0–1 vehicles/min) were 15% lower. Once elk entered an underpass, semi-trailer trucks were 4 times more likely than passenger vehicles to cause flight behavior when traffic levels were intermittent versus when traffic was continuous. Overall, traffic volumes of >10–27 vehicles per minute did not decrease the effectiveness of wildlife underpasses as a means of mitigating elk population subdivision. However, if flight away from underpasses at intermediate traffic levels causes elk to cross the highway at other points and thereby increases the potential for costly elk–vehicle collisions, we recommend that managers consider measures to reduce traffic noise and visual stimuli, especially those caused by semi-trailer trucks. (JOURNAL OF WILDLIFE MANAGEMENT 71(7):2324–2328; 2007)

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As roads around the world upgrade and expand to accommodate increasing traffic volume, the need to maintain wildlife permeability while simultaneously reducing wildlife–vehicle collisions also increases. Structures that allow wildlife to safely cross under and over highways are implemented increasingly as mitigation measures (Romin and Bissonette 1996, Danielson and Hubbard 1998). Traffic could reduce the effectiveness of these wildlife-crossing structures if wildlife responded 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 use of crossing structures (Foster and Humphrey 1995, Gloyne and Clevenger 2001, Plumb et al. 2003, Ng et al. 2004, Clevenger and Waltho 2005) and some have also documented animal behavior during crossings (Reed et al. 1975, Reed 1981, Gordon and Anderson 2003, Dodd et al. 2007*b*). Although Singer and Doherty (1985) documented a decline in underpass use by mountain goats (*Oreamnos americanus*) when vehicles were present, no studies have examined the direct influence of variation in traffic volume on wildlife crossing behavior at wildlife underpasses. Reed et al. (1975) and Gordon and Anderson (2003) documented various behaviors of mule deer (*Odocoileus hemionus*) while using underpasses, assuming these behaviors were based solely on the structural attributes of the underpasses. Traffic was not documented during these studies and, as Forman et al. (2003:276) point out, "the response of an individual animal to the movement of different types of vehicles remains an important research frontier."

To address this need, we examined the effects of traffic volume and vehicle type (tractor-trailers [semis] vs. passenger vehicles) on Rocky Mountain elk (*Cervus elaphus*) during their use of wildlife underpasses constructed during the upgrading of a 2-lane rural highway to a 4-lane divided highway. We examined the effect of traffic in light of 3 other factors that could influence the behavioral response to traffic: 1) whether elk responded similarly at different underpasses, 2) whether elk responded similarly during both migratory periods (when nonresident elk were moving through our area) and during nonmigratory periods, and 3) whether lone elk or elk in small (2–5) or larger (>5) groups responded similarly. Our objective was not to determine the relative importance of the various factors that affected overall passage rates (e.g., underpass design and location), but more specifically to evaluate whether the effect of traffic volume on the probability of successfully passing through an underpass was consistent across these factors. We focused on elk for these analyses because 1) they had a history of frequent collisions with vehicles on this highway (Dodd et al. 2006) and, therefore, factors affecting use of underpasses had immediate management implications, 2) they were by far the most abundant species using these crossing structures, and 3) their size allowed behavior to be more accurately documented using video surveillance.

STUDY AREA

We studied elk at 4 underpasses along a 27-km stretch of Arizona State Route 260 (SR 260) approximately 15 km east of Payson, Arizona, USA. The study area rose in

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elevation gradually from 1,590 m to 2,000 m, and vegetation type changed accordingly with pinyon–juniper (*Pinus edulis*, *Juniperus* spp.) and interior chaparral (primarily manzanita; *Arctostaphylos pungens*) at the lower elevations giving way to ponderosa pine (*Pinus ponderosa*) at the upper end of the study area (Brown 1994). The Mogollon Rim, an escarpment that is the dominant landform in the area, rises just north of the study area. Elk using the underpasses during our study likely represent 2 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 above and below the rim (Brown 1990, Dodd et al. 2006). Mean annual daily traffic volumes on this portion of SR 260 increased from 3,200 vehicles in 1993 to 8,700 vehicles in 2003 (Arizona Department of Transportation [ADOT] 2005). Since 1993, elk–vehicle collisions have ranged from 1 collision/km to 10 collisions/km per year along this stretch of highway.

METHODS

The 4 wildlife underpasses we studied were constructed between 2001 and 2004. We recorded elk behavior from May 2003 through July 2006. Time since underpass completion varied across underpasses, ranging from a few days to >1 year. Underpasses varied in design and placement, though all were located in natural drainages. Fencing extended ≤1 km on either side of underpasses, but the remainder of this 27-km stretch of highway was not fenced. We used a video surveillance system consisting of 4 cameras triggered by infrared beams (Gagnon et al. 2006, Dodd et al. 2007*b*) to simultaneously monitor traffic and behavior of elk that approached within 50 m of each underpass (Fig. 1). We defined an approach as animals that crossed the highway right-of-way fence (approx. 50 m from the roadway) and moved toward the underpass. We determined elk passage rates by dividing the number of successful passages by the number of approaches. Because the behavior of herd members can be influenced by a lead animal, we counted each group of elk as a single data point, and considered events where >50% of the herd passed through the underpass as successful transits. We calculated traffic volume for a passage event as vehicles per minute by dividing the total number of vehicles recorded by the camera aimed at the roadway during the time animals were present, by the total amount of time an individual elk or group of elk spent in the area until either passing through the underpass or leaving the field of view.

To examine the overall effect of traffic volume on passage rates, we compared the proportion of animals that successfully crossed at each of 6 traffic levels (0, >0–1, >1–3, >3–6, >6–10, and >10–27 vehicles/min) using a chi-square contingency table (Agresti 1996). We then subdivided and graphed the proportion of successful crossings at each traffic level for each underpass, migratory (Oct–Mar) and non-migratory period (Apr–Sep), and for 3 group-size categories (1, 2–5, or >5 elk). Less than 5% of our observations were at traffic levels >10 vehicles per minute; therefore, we did not include this category in these subset graphs due to small sample size.

To determine if vehicle type affected elk once they entered underpasses, we assigned 3 behaviors to each animal that had a passenger vehicle or semi-trailer truck pass overhead: 1) no response—elk that showed no reaction to vehicles passing overhead during crossing or were already stationary prior to vehicle(s) passing overhead, 2) delay—elk that showed hesitation while crossing at the moment a vehicle passed overhead but then proceeded through the underpass, and 3) flight—elk that showed a retreat or flight behavior at the moment a vehicle passed overhead, thereby leading to an unsuccessful crossing. We compared the number of each behavior exhibited when passenger vehicles were present and when semis were present using a chi-square contingency table test (Agresti 1996). We used a Cochran–Mantel–Haenszel (CMH) test to determine if effects of vehicle type were dependent on traffic level (Agresti 1996). This is a test of conditional independence, with a null hypothesis that elk response is independent of vehicle type across high and low traffic levels. We used a 3-way contingency table (Agresti 1996) to test the combined effects of vehicle type and traffic level. Due to small sample sizes in some categories, we did not use the same traffic categories as in other analyses, and instead collapsed traffic into low (<4 vehicles/min) versus high (>4 vehicles/min). Using a simple logit model, we estimated the conditional odds ratio of the effect of semis versus passenger vehicles at the different traffic levels, 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).

RESULTS

We analyzed 200 hours of elk behavior and documented 993 approaches (2,857 individual elk in groups of varying sizes). When we compared passage rates at 6 traffic levels across all 993 approaches, traffic level had a statistically significant effect on probability of elk successfully transiting an underpass ($\chi^2 = 34.6$, df = 5, $P < 0.001$). However, this was driven primarily by both a decrease in passage rates at the >0–1–vehicles-per-minute category, which contributed 62% to the overall chi-square statistic and a less-pronounced increase at the 3–6–vehicles-per-minute category (30% of the overall χ^2; Table 1). This same pattern was evident in both migratory and nonmigratory periods, at 2 of 3 underpasses and at 2 of 3 group sizes (Fig. 2). We did not include the fourth underpass in the latter graphs due to low sample sizes (<5) at some traffic levels.

Vehicles passed directly overhead of individual elk during 780 passages, with 633 and 147 involving passenger vehicles and semis, respectively. Semis were associated with elk flight from the underpasses 36.7% of the time, whereas passenger vehicles caused flight 17.2% of the time ($\chi^2 = 25.6$, df = 1, $P < 0.001$). This flight response was dependent on traffic level (CMH $\chi^2 = 27.3$, df = 1, $P < 0.001$). When traffic levels

Table 1. Number of successful and unsuccessful transits and passage rates by elk at 6 traffic volumes at 4 wildlife underpasses along State Route 260, Arizona, USA, 2003–2006.

	Traffic category (vehicles/min)					
	No vehicles	>0–1	>1–3	>3–6	>6–10	>10–27
Successful	60	163	211	143	59	28
Unsuccessful	27	137	89	40	26	10
Passage rate	0.69	0.54	0.70	0.78	0.69	0.74

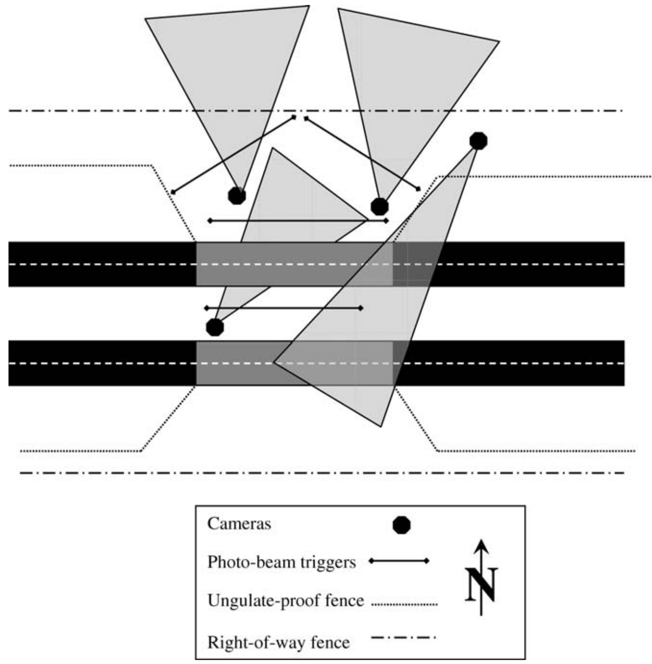

Figure 1. Typical layout of 4-camera video surveillance system triggered by infrared detectors installed at each wildlife underpass, which allowed simultaneous viewing of elk in and around the underpass and corresponding traffic passing overhead, Arizona, USA, 2003–2006.

were <4 vehicles per minute, semis were 5 times more likely than passenger vehicles to cause a flight response ($\chi^2 = 44.6$, df = 1, $P < 0.001$), whereas when traffic levels were relatively continuous (>4 vehicles/min), flight behavior was not different for passenger vehicles and semis ($\chi^2 = 0.008$, df = 1, $P = 0.930$; Table 2).

DISCUSSION

We found no evidence that increasing traffic passing over wildlife underpasses acted as a moving fence (Bellis and Graves 1978) that reduced underpass use by elk. This pattern contrasts with that in a concurrent study of elk crossing the same highway at locations away from underpasses (Gagnon et al. 2007), in which the probability of crossing highways once animals came within 250 m declined with increasing traffic volume. This comparison suggests that traffic volume does not deter elk from using underpasses in the same way similar traffic levels deters them from crossing the highway itself. Therefore, wildlife underpasses have the potential to effectively mitigate population fragmentation caused by high traffic volume on highways.

Unexpectedly, we found passage rates 15% lower at low, intermittent traffic volume, a pattern evident in overall passage rates, at 2 of the 4 underpasses, across migratory periods, across group sizes, and in the stronger effects of tractor-trailers versus automobiles only at lower traffic levels. In all cases, this response may have been due to elk reacting to the shock created by the sudden sound and visual stimuli of a single vehicle passing by during periods of relative quiet compared to the relatively continuous stream of passing vehicles (Forman et al. 2003). Although both auditory and visual stimuli could cause flight at low traffic levels during an approach, once elk entered underpasses, response to traffic was more likely due to sound or vibration. The greatest increase in traffic noise occurs up to approximately 10,000 vehicles per day. From 1 vehicle per day to 10,000 vehicles per day, sound increases to 70 A-weighted decibels (dBA), whereas an increase from 12,000 vehicles per day to 36,000 vehicles per day only increases 1–2 dBA (Forman et al. 2003). The average annual daily traffic during this study was approximately 8,000 vehicles per day, allowing elk and other wildlife along this stretch of roadway to experience the greatest fluctuations in sound levels associated with varying traffic. The increased flight caused by semis was likely due to the sound created by larger vehicles; a heavy truck passing by on the road produces approximately 10 dBA more noise then that of passenger vehicles (Lee and Fleming 1996).

Although animals fleeing from an underpass at low, intermittent traffic may simply return to the underpass at another time, alternatively they could attempt to cross the highway at another location, thereby increasing the potential for elk–vehicle collisions. Given the high cost of these collisions, economically and in terms of human and elk mortality, modifications that reduce the sound of vehicles passing directly overhead, particularly semis, could be merited if elk that flee underpasses cross the highway at other locations where they are a danger to motorists. Alternatively, fencing could be used to both funnel animals toward underpasses and prevent those fleeing underpasses from crossing the highway at other locations. For example, installing fencing in areas with wildlife crossing structures reduced ungulate–vehicle collisions by 86% in central Arizona (Dodd et al. 2007*a*).

Although elk living near highways year-round would be predicted to be less sensitive to traffic than animals that migrate through seasonally, we did not detect a reduction in passage rates with increasing traffic volumes during migratory periods when elk less familiar with traffic and passage structures were present. However, although elk approached underpasses at similar rates during the migratory period and nonmigratory period, passage rate was overall lower during the migratory period at all traffic levels, consistent with other studies at this site (Dodd et al. 2007*b*). We hypothesize that the higher passage rates during nonmigratory, late spring–summer periods was driven by increased motivation to pass through underpasses due to the

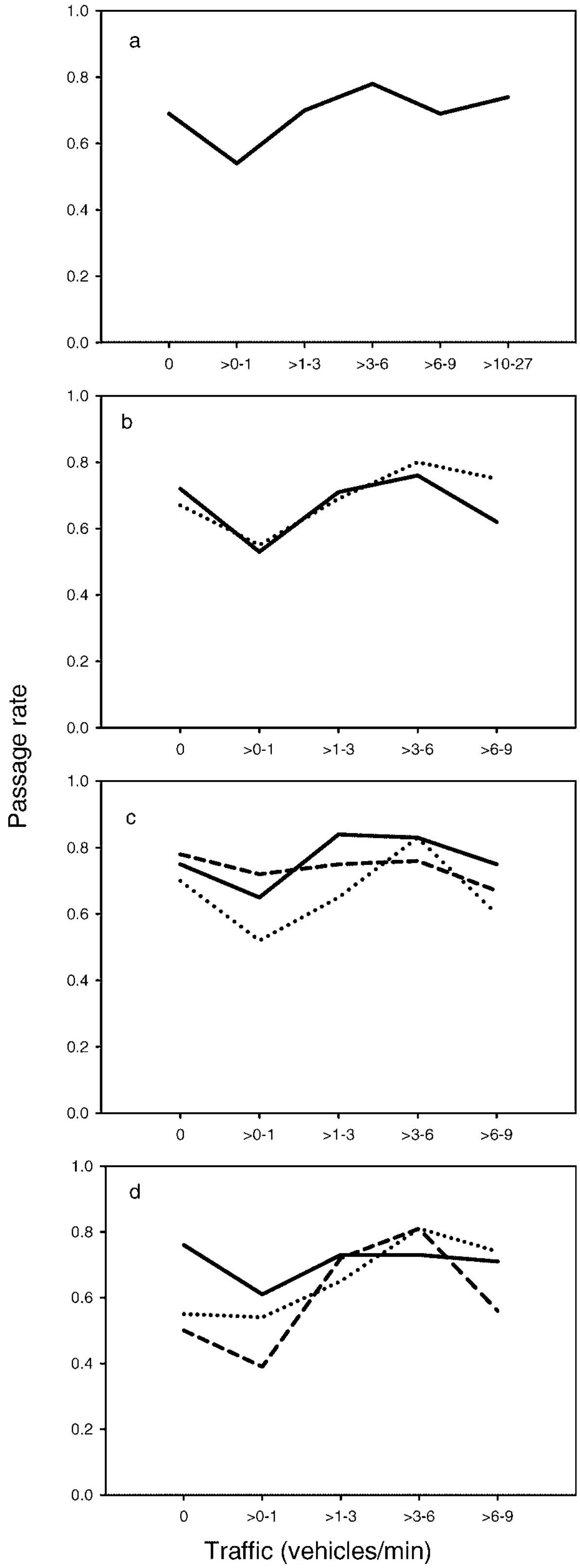

Figure 2. Passage rates for elk using wildlife underpasses at different traffic volumes along State Route 260, Arizona, USA, 2003–2006. a) overall, b) by season (solid line = nonmigratory [winter and summer], dotted line = migratory [autumn and spring]), c) across 3 different wildlife underpasses, and d) across 3 group sizes (solid line = single individual, dotted line = 2–5 individuals, dashed line = >5).

Table 2. Number and proportion of individual elk exhibiting flight responses while passenger vehicles and semis passed overhead at low and high traffic levels during attempted crossings at 4 wildlife underpasses along State Route 260 in central Arizona, USA, 2003–2006.

Vehicle type	<4 vehicles/min Flight	Total	Proportion	>4 vehicles/min Flight	Total	Proportion
Passenger	57	344	0.17	52	289	0.18
Semi	42	82	0.51	12	65	0.19
Total	99	426	0.23	64	354	0.18

availability of high-quality forage in riparian meadows at these times of the year.

Although elk may be more likely to tolerate negative stimuli when in a group (Borkowski et al. 2006), we found no evidence for elk in groups to react differently to traffic volume than when alone. A lead female or dominant male may drive much of the behavior associated with elk underpass crossings. In many of our 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 male, or several males, either herded or led a group of females through the underpass. As a result, the sensitivity to underpasses or traffic of a relatively small subset of the population, lead females and dominant males, may have important repercussions for the remainder of elk in an area.

All of the underpasses we monitored were located in areas that linked important habitat components for elk, and the attractiveness of these resources may have influenced the lack of response to traffic we documented. In a study of highway crossings by radiocollared elk along the same stretch of highway, Gagnon et al. (2007) showed that traffic levels elk tolerated when crossing highways was higher in locations near the riparian meadows that are an important resource for elk in this region. Given that the underpasses studied here were also associated with relatively rich riparian areas, elk may have tolerated traffic on underpasses in part due to higher motivation to access these feeding areas. Structural attributes and proper placement of individual underpasses is key to the success of a wildlife underpass (Beier and Loe 1992, Foster and Humphrey 1995, Clevenger and Waltho 2000, Gagnon et al. 2006, Dodd et al. 2007*b*), and because increasing traffic levels are likely unavoidable in the future, this underscores the need for proper underpass design and placement.

MANAGEMENT IMPLICATIONS

High traffic volume highways can potentially act as impermeable barriers to wildlife, but we found no evidence that higher traffic volumes reduced elk use of wildlife underpasses, indicating that wildlife underpasses remain an effective means of mitigating population subdivision even when traffic volume is high. However, lower traffic volumes that result in intermittent vehicle passage may cause increased flight by elk, especially when those vehicles are semi-trailer trucks. Given that these animals may attempt to cross the highway at other points, thereby increasing the probability of elk–vehicle collisions, we recommend that highway fencing and methods to reduce the visual and auditory stimuli associated with traffic be considered at crossing structures.

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