Traffic Volume Alters Elk Distribution and Highway Crossings in Arizona

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ABSTRACT We used 38,709 fixes collected from December 2003 through June 2006 from 44 elk (*Cervus elaphus*) fitted with Global Positioning System collars and hourly traffic data recorded along 27 km of highway in central Arizona, USA, to determine how traffic volume affected elk distribution and highway crossings. The probability of elk occurring near the highway decreased with increasing traffic volume, indicating that elk used habitat near the highway primarily when traffic volumes were low (<100 vehicles/hr). We used multiple logistic regression followed by model selection using Akaike's Information Criterion to identify factors influencing probability of elk crossings. We found that increasing traffic rates reduced the overall probability of highway crossing, but this effect depended on both season and the proximity of riparian meadow habitat. Elk crossed highways at higher traffic volumes when accessing high quality foraging areas. Our results indicate that 1) managers assessing habitat quality for elk in areas with high traffic-volume highways should consider that habitat near highways may be utilized at low traffic volumes, 2) in areas where highways potentially act as barriers to elk movement, increasing traffic volume decreases the probability of highway crossings, but the magnitude of this effect depends on both season and proximity of important resources, and 3) because some highway crossings still occurred at the high traffic volumes we recorded, increasing traffic alone will not prevent elk–vehicle collisions. Managers concerned with elk–vehicle collisions could increase the effectiveness of wildlife crossing structures by placing them near important resources, such as riparian meadow habitat. (JOURNAL OF WILDLIFE MANAGEMENT 71(7):2318–2323; 2007)

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Roads can negatively impact wild ungulates by altering habitat use (Lyon 1979, Rost and Bailey 1979, Rowland et al. 2000), restricting movements and thereby genetically subdividing populations (Forman et al. 2003, Epps et al. 2005) and increasing mortality through collisions with vehicles (Groot Bruinderink and Hazebroek 1996, Forman et al. 2003). The magnitude of all of these factors likely increases with increasing traffic volume. For example, elk (*Cervus elaphus*) more strongly avoid areas near forest roads with higher traffic levels (Perry and Overly 1976, Witmer and deCalesta 1985, Rowland et al. 2000, Wisdom et al. 2005), leading to the hypothesis that increased traffic should result in decreasing habitat effectiveness (Lyon 1979, Lyon and Christensen 1992). Likewise, increasing rates of ungulate–vehicle collisions are often correlated with increasing traffic volume (Allen and McCullough 1976, Groot Bruinderink and Hazebroek 1996, Romin and Bissonette 1996), though the relationship is often not linear, suggesting complex interactions with behavior, ungulate population density, and landscape-level phenomena (Groot Bruinderink and Hazebroek 1996, Seiler 2004). Finally, several recent theoretical models (Iuell et al. 2003, Jaeger et al. 2005) assume that the potential for traffic to act as an impermeable moving fence (Bellis and Graves 1978) increases with traffic volume.

Traffic volume on any roadway varies seasonally, weekly, and with time of day, and animals may respond to these temporal fluctuations. For example, elk in Oregon, USA, showed a consistent diurnal pattern of movement relative to low traffic-volume forest roads that were open to traffic, moving closer at night and farther away during the day (Ager et al. 2003). Likewise, most highway crossings by grizzly bears (*Ursus arctos*) in Montana, USA, occurred at night when traffic counters documented traffic volume was lowest (Waller and Servheen 2005). These studies underscore the need to link how animals respond to highways with temporal fluctuations in traffic.

Although several studies have documented elk response to relatively low traffic-volume roads (Hershey and Leege 1976, Perry and Overly 1976, Rowland et al. 2000, Wisdom et al. 2005) previous studies have not examined the potentially greater effects of varying traffic levels on elk distributions and movements along highways (Ruediger et al. 2006). Furthermore, previous studies compared elk distributions among different areas of roadway or using road type as a surrogate for increasing traffic levels (Rost and Bailey 1979, Witmer and deCalesta 1985), potentially confounding the effect of traffic with differences in habitat, resource type and availability, and human disturbance. In this study, we examined the effects of fluctuating hourly traffic rates on the distribution and movements of elk in central Arizona along 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 factors to determine the probability of elk crossing the highway.

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STUDY AREA

Our study focused on 27 km of State Route (SR) 260, approximately 15 km east of Payson, Arizona, USA. The Mogollon Rim escarpment was the dominant land feature in the area. The study area rose gradually from 1,590 m to 2,000 m, and vegetation type changed accordingly with pinyon (*Pinus edulis*)–juniper (*Juniperus* spp.) and chaparral (*Arctostaphylos* spp.) at lower elevations giving way to ponderosa pine (*P. ponderosa*) and pockets of Douglas fir (*Pseudotsuga menziesii*) at the upper end of the study area (Brown 1994). At several points, the highway ran along riparian areas that supported wet meadows favored by elk as foraging areas (Dodd et al. 2007*a*). This roadway has produced high numbers of elk–vehicle collisions with some sections experiencing as many as 10 collisions/km per year since 1993 (Dodd et al. 2006).

METHODS

We estimated traffic volume using a permanent traffic counter programmed to record mean hourly traffic volumes. We installed the traffic counter in December 2003 at the center of the study area. 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 1-hour interval.

We obtained Global Positioning System (GPS) relocations from 44 elk (7 M, 37 F) radiocollared with store-on-board collars (model TGW-3600; Telonics, Inc., Mesa, AZ) from 2001 through 2006 (Dodd et al. 2007*a*). We recovered all of our collars by June 2006, providing approximately 30 months of data concurrent with operation of our traffic counter. We accrued GPS fixes at 2-hour intervals, and were accurate to ± 10 m (Dodd et al. 2006). We only used fixes recorded during 1700–0800 hours because this was the period elk were most active and $<3\%$ of highway crossings occurred outside of this period (Gagnon 2006). We combined traffic and GPS data by assigning traffic volumes for the previous hour to each GPS location using ArcGIS Version 9.1.

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 100-m distance band, out to a maximum of 600 m (similar to Rowland et al. 2005). 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 100-m 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 2 different behaviors: 1) movement near the highway in which crossing was not detected, and 2) movement that resulted in successive relocations on opposite sides of the highway (crossing occurred). We defined a noncrossing movement as those instances when the 2 successive GPS relocations indicated elk entered the 250-m zone adjacent to the highway from beyond that distance but did not cross the highway. We chose the 250-m zone based on the mean movement of elk during crossing events. Because the upper limit of the 99% confidence interval for highway crossings by all elk during this study was <600 m, we assumed $<1\%$ of elk could enter this 600-m zone (250 m on each side of the 100-m highway footprint) from either direction and cross the highway without being detected.

Our primary focus in this analysis was determining the effect that varying traffic volumes had on the probability of elk crossing SR 260. In addition to traffic, we identified 4 other factors that potentially influence elk movement near roads or are associated with higher elk–vehicle collision rates based on prior studies. 1) Previous studies have demonstrated that elk respond to presence of riparian meadow habitat adjacent to roadways (Ward 1976; Dodd et al. 2006, 2007*a*; Manzo 2006). We considered wet meadows and areas along streams within 1 km of the highway as adjacent. 2) Frequency and patterns of elk movements to and from feeding areas and seasonal use areas can vary across the year (Groot Bruinderink and Hazebroek 1996, Gunson and Clevenger 2003, Dodd et al. 2006). We defined 4 seasons based on local climatic conditions and elk behavior as winter (Dec–Feb), spring (Mar–May), summer (Jun–Aug), and fall (Sep–Nov). 3) Due to differing reproductive and nutritional drives, sexes may differ in their response to traffic (Marcum and Edge 1991, Gunson and Clevenger 2003, McCorquodale 2003, Dodd et al. 2006). 4) Although we limited our analysis to the hours between dusk and dawn, activity patterns can vary with time of night (Groot Bruinderink and Hazebroek 1996, Haikonen and Summala 2001, Dodd et al. 2006). We defined 3 time periods during which elk motivation to move from one area to another could potentially vary: 1) evening, 1700–2159 hours, to include dusk, sunset, and the hours immediately following sunset; 2) night, 2200–0259 hours; and 3) morning, 0300–0800 hours to include twilight, sunrise, and time immediately following sunrise.

We used Akaike's Information Criterion (AIC; Burnham and Anderson 2002) to select the most parsimonious model among a suite of 23 models (Table 1). A model was considered a candidate if it had a ΔAIC <10. We used a goodness-of-fit test to check fit of the selected model(s) versus the saturated model (Agresti 1996). Once we selected the best possible model(s) and tested for adequate fit, for ease of interpretation, we converted the log odds models into probabilities using:

$$\text{probability} = \left[\frac{\exp(\alpha + \beta x + \ldots)}{1 + \exp(\alpha + \beta x + \ldots)}\right].$$

We then used these equations to create a graphical model of the probability of elk crossing the highway under these scenarios.

Table 1. Results of model selection for 23 candidate models using Akaike's Information Criterion (AIC) that describe the probability of 40 elk crossing State Route 260 in Arizona, USA, 2003–2006. Each model is listed with its number of parameters (K), AIC, AIC difference (ΔAIC), and Akaike weights (w_i).

Model	K	AIC	ΔAIC	w_i
Traffic + season + meadow	4	6,225	0	0.9997
Traffic + time +meadow	4	6,241	16	0.0003
Traffic + meadow	3	6,245	20	<0.001
Traffic + meadow + sex	4	6,245	20	<0.001
Meadow + season + time	4	6,245	20	<0.001
Traffic + season + time	4	6,253	28	<0.001
Traffic + season	3	6,257	32	<0.001
Traffic + season + sex	4	6,257	32	<0.001
Meadow + season	3	6,262	37	<0.001
Meadow + time	3	6,268	43	<0.001
Traffic + time	3	6,275	50	<0.001
Traffic + sex + time	4	6,275	50	<0.001
Traffic	2	6,279	54	<0.001
Season + time	3	6,279	54	<0.001
Traffic + sex	3	6,279	54	<0.001
Sex + time	3	6,279	54	<0.001
Meadow	2	6,284	59	<0.001
Meadow + sex	3	6,284	59	<0.001
Season	2	6,295	70	<0.001
Season + sex	3	6,295	70	<0.001
Time	2	6,303	78	<0.001
Null	1	6,319	94	<0.001
Sex	2	6,319	94	<0.001

RESULTS

Total monthly traffic for December 2003–June 2006 ranged from 120,129 vehicles to 330,011 vehicles and totaled 6,470,211 vehicles. Hourly traffic volumes during the peak elk movement period of 1700–0800 hours ranged from 1 vehicle/hour to 1,514 vehicles/hour and averaged 300 vehicles/hour (95% CI = 296, 304).

We based our distribution analysis on 38,709 GPS relocations recorded within 600 m of the highway between 1700 hours and 0800 hours. 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 occurring within 200 m of the highway approximately 40% at <100 vehicles/hour and dropping to less than 20% when traffic was 600 vehicles/hour (Fig. 1).

We based our highway crossing probability analysis on 15,608 movements that occurred within 250 m 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 ($\bar{x}$ = 467 m, 95% CI = 448, 486) than during noncrossing movements ($\bar{x}$ = 253 m, 95% CI = 248,258).

Our AIC model selection process yielded only one model that was supported under the AIC criteria (ΔAIC < 10); this model included traffic volume, riparian meadow habitat, and season (Table 1). Model fit was adequate for continued analysis ($\chi^2 = 3579$, df = 3583, $P = 0.51$). Using coefficients derived from this model (Table 2), we created graphs representing the probability of crossing for each traffic–meadow–season combination (Agresti 1996; Fig. 2). Although in each case the probability of crossing decreased with increasing traffic volume, the probability of crossing at any given traffic volume was highest during the spring and fall seasons in areas where riparian meadow habitat was present, followed in decreasing order by winter and summer

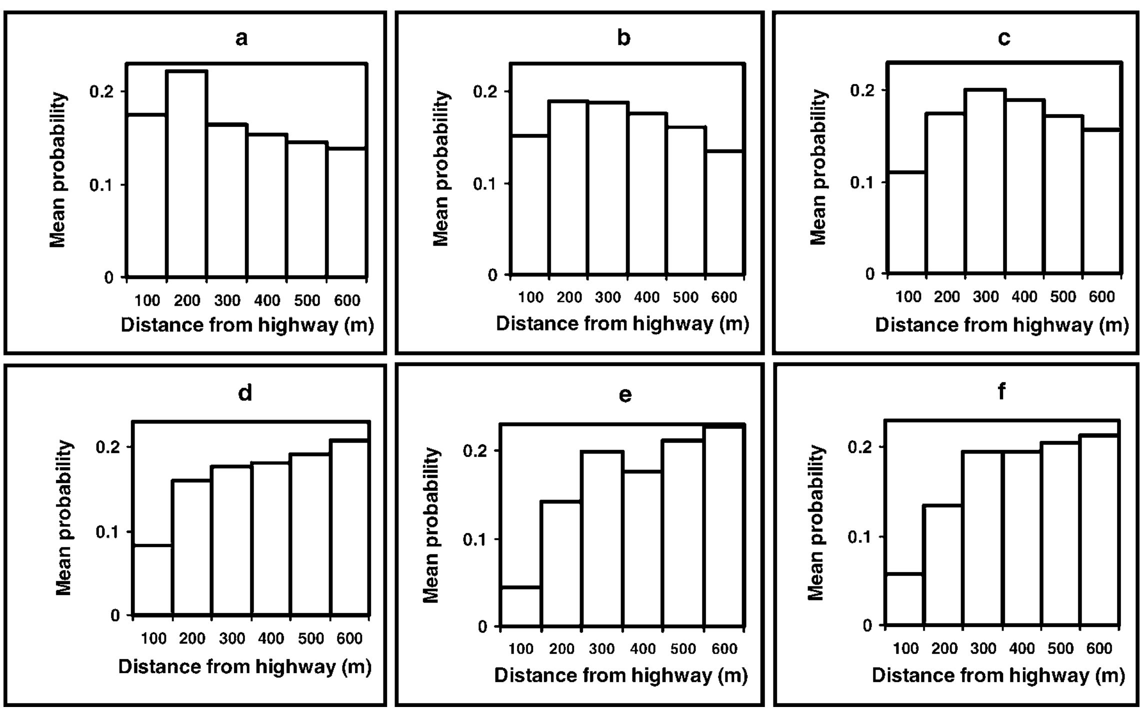

Figure 1. Mean probability that radiocollared elk (n = 44) occurred within each 100-m distance band from the highway at varying traffic volumes, State Route 260, Arizona, USA, 2003–2006: (a) <100 vehicles/hour, (b) >100–200 vehicles/hour, (c) >200–300 vehicles/hour, (d) >300–400 vehicles/hour, (e) >400–500 vehicles/hour, (f) >500 vehicles/hour.

Table 2. Logistic regression output obtained following model selection for the probability of 40 elk crossing State Route 260, Arizona, USA, 2003–2006. Each model is listed with its coefficient (β), standard error, Wald chi-square, degrees of freedom, *P* values, and odds.

Variable	β	SE	χ^2	df	*P*	Odds
Traffic volume[a]	−0.001	0.0001	75.49	1	<0.001	0.99
Meadow, present	0.58	0.067	66.99	1	<0.001	1.79
Season						
Winter	−0.16	0.047	10.99	1	<0.001	0.85
Spring	0.17	0.04	18.92	1	<0.001	1.18
Summer	−0.15	0.04	12.25	1	<0.001	0.86
Fall	0.14	0.037	13.23	1	<0.001	1.15
Intercept	−1.09	0.07	237.11	1	<0.001	0.34

[a] Continuous variable, all others categorical.

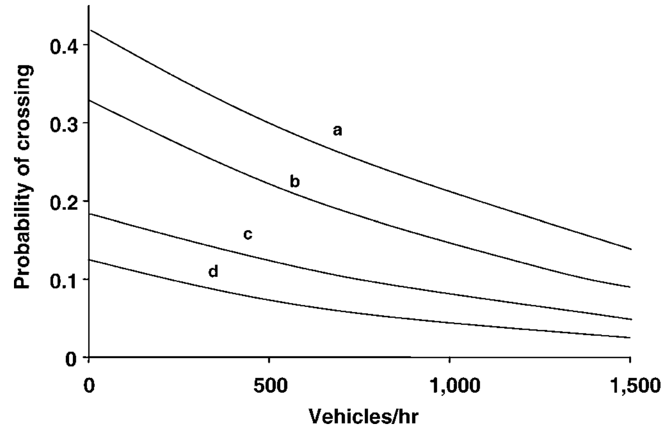

Figure 2. Probability that elk would cross the highway at varying traffic volumes under different scenarios, derived from the best possible model selected using Akaike's Information Criterion, along State Route 260, Arizona, USA, 2003–2006. (a) spring or fall, meadow present; (b) winter or summer, meadow present; (c) spring or fall, no meadow present; (d) winter or summer, no meadow present.

seasons in areas with meadows present, spring and fall seasons with no meadow present, and winter and summer seasons in areas with no meadow present.

DISCUSSION

Traffic Volume and Elk Distribution

Although negative responses of elk to low traffic-volume roads (Lyon 1979, Witmer and deCalesta 1985, Rowland et al. 2000, Wisdom et al. 2005) suggested that "persistent road-mediated disturbance may lead to permanent shifts in habitat use by elk" (Rowland et al. 2000:681), we did not find a permanent shift away from the highway even though traffic levels were nearly 10-fold greater than in these other studies. 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, similar to responses documented on lower volume forest roads (Morgantini and Hudson 1979, Ager et al. 2003). This pattern is broadly consistent with models of roads resulting in reduced habitat effectiveness (Lyon 1979, 1983), defined as "percentage of available habitat that is usable by elk outside the hunting season" (Lyon and Christensen 1992:4). 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 in the arid southwestern United States (Dodd et al. 2006, 2007*a*; Manzo 2006).

Traffic Volume, Probability of Highway Crossing, and Highway Permeability

As traffic volume increased from zero to 1,500 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 2 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). As a result, part of the interaction between season and traffic volume may have been due to increased attractiveness of meadows in spring. In addition, some of the elk in our study crossed the highway during migratory movements between summer and winter ranges in both fall and spring. The elevational gradient across our study area is extremely steep, so migrational movements 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 reflect the combination of the absence of strong unidirectional 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 males have been documented to have higher sensitivity to roads than females (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. (2006, 2007*a*) 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 context; 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.

Elk Distribution and Collisions

The spatial response of elk to traffic volume 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 partly explain 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 (*Odocoileus virginianus*; Allen and McCullough 1976) in which the number of collisions was 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 or when elk that have moved farther from the highway to avoid higher traffic volumes make long-distance, directed movements to access the riparian meadows common along this stretch of highway. Given the potential for wildlife crossing structures to safely convey animals across highway corridors (Foster and Humphrey 1995, Clevenger and Waltho 2005, Gagnon et al. 2006, Dodd et al. 2007*b*), our data indicate that placing these structures near meadows could allow elk to pass safely to and from these areas in both migratory and nonmigratory seasons, thereby reducing the probability of elk–vehicle collisions at high traffic volumes.

MANAGEMENT IMPLICATIONS

Elk use of areas near a relatively high traffic-volume highway depended on traffic volume; therefore, 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. Traffic volume, season, and proximity to meadows interacted to determine the probability of highway crossing by elk, therefore modeling the impact of traffic volume on highway permeability to elk must consider the larger landscape context. Both the tendency for elk to shift closer to the highway at lower traffic volumes and to cross the highway at higher traffic volumes during migratory periods or near meadows could increase the potential for elk–vehicle collisions. Therefore, placing wildlife crossing structures near meadows could allow elk to pass safely to and from these areas in both migratory and nonmigratory seasons.

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