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EFFECTS OF ROADWAY TRAFFIC ON WILD UNGULATES: A REVIEW OF THE LITERATURE AND A CASE STUDY OF ELK IN ARIZONA

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Abstract: Roads have been recognized as a threat to wildlife species for over 80 years. Studies on the effects of roads on ungulates species did not begin till the 1970's. We identified 53 literature sources that suggested or examined traffic levels or road types and their effects on ungulate-vehicle collisions, ungulate distribution and roadway permeability. Seventy-one percent of these suggested an effect of traffic level on ungulates. Only 47% of the papers suggested deer (*Odocoileus spp.*) were affected by traffic while in contrast studies on elk (*Cervus elaphus*) and moose (*Alces alces*) were at 84% and 82%, respectively. In studies that suggested no effect of traffic, other factors such as ungulate populations, ungulate behavior, driver behavior, and landscape variables were generally considered reasons for fluctuations in collisions. Although several studies examined ungulate distribution along roads, very few adequately looked at fluctuating traffic levels along highways. Highways have a greater potential for ungulate-vehicle collisions and are more likely to provide a barrier to ungulates than low traffic roads. Our further understanding of ungulate movements and behavior in relationship to highways may be important in helping to mitigate ungulate-vehicle collisions and ungulate habitat fragmentation. Our State Route 260 project in central Arizona has provided a unique opportunity to examine elk movements in relation to traffic along a highway. We documented distinct shifts in distribution associated with fluctuating traffic levels as well as reductions in probabilities of at-grade crossings during increasing traffic levels. During the same study we found that increased traffic levels did not alter elk use of wildlife underpasses. Overall, properly designed wildlife underpasses and adequate funnel fencing adequately reduced elk-vehicle collisions while simultaneously promoting highway permeability during increasing traffic levels. Further research is needed to determine if these trends hold true for other ungulate species. Currently, research of fluctuating hourly traffic levels on ungulate behavior associated with highways is underway in Arizona, including American pronghorn (*Antilocapra americana*), mule deer (*O. hemionus*), Coues' white-tailed deer (*O. virginianus couseii*) and further research on elk along highways with different geographical areas and traffic level ranges.

Introduction

Researchers as early as the 1920's and 30's began taking road trips and documenting wildlife-vehicle collisions associated with vehicle caused mortality (Stoner 1925, 1936; Gordon 1932, Warren 1936 *a,b*; Starrett 1938, Russel and Amandon 1938, Dickerson 1939). Very few of these early studies found ungulate casualties. Only Haugen (1944) and Davis (1939) documented a total of four pigs killed between the both of their studies. It was not until the 1970's that larger wildlife, such as ungulates, became a concern as traffic levels and vehicle speeds increased, leading to higher rates of ungulate-vehicle collisions. In the1970's researchers began to investigate the potential direct and indirect effects of roads and traffic on ungulates.

Roads and traffic have three primary affects on ungulates populations in the form of: 1) ungulate-vehicle collisions, 2) reduced habitat/resource selection, and 3) decreased movement across roadways leading to habitat fragmentation and potentially genetic isolation.

Ungulate-Vehicle Collisions

In the United States alone, it is estimated that 700,000 (Schwabe & Schuhmann 2002) to >1 million (Conover et al. 1995) deer-vehicle collisions occur, with associated costs that exceed $1 billion (Conover et al. 1995) to $2 billion (Danielson & Hubbard 1998). In Europe an estimated 300 people are killed, and 30,000 injured in >500,000 ungulate-vehicle collisions annually (Groot Bruinderink & Hazebroek 1996). Although researchers disagree about whether increasing traffic levels are the primary reason for increasing ungulate-vehicle collisions (McCaffery 1973; Reilly & Green 1974; Allen & McCullough 1976; Case 1978; Romin & Bissonette 1996), many recognize traffic level as a component of this increase, 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 Buinderink & Hazebroek 1996, Haikonen & Summala 2001, Seiler 2004, Gunson and Clevenger 2003, Manzo 2006)

Reduced Habitat/Resource Selection

Roads and the traffic associated with them have presumed effect on ungulate resource potentially reducing the amount of resources available to ungulates, or decreased "habitat effectiveness" (Lyon and Christensen 1992, Lyon 1983). Overall, areas near roads are inhabited less frequently by some ungulates, particularly as traffic levels increase (Rowland et al. 2000, Perry and Overly 1976, Gagnon et al. 2007*a*)

Permeability/Habitat Fragmentation/Genetic Isolation

Increase in the overall number and width of roads throughout the world increases fragmentation of available ungulate habitat. This is particularly evident along roads with high traffic levels such as highways on wildlife are barrier and fragmentation effects resulting in diminished habitat connectivity and permeability (Noss and Cooperrider 1994, Forman et al. 2003). Highways block animal movements between seasonal ranges or other vital habitats (Trombulak and Frissell 2000). This barrier effect fragments habitats and populations, reduces genetic interchange (Epps et al. 2005, Riley et al. 2006), 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 stochastic events that may lead to extinctions (Hanski and Gilpin 1997).

The "road-effect zone" (Forman and Deblinger 2000) is "many times wider than the road itself"; traffic, or the "traffic effect zone" is a key component of the overall road effect zone and includes increases in visual stimuli, sound, vibration, and pollution with increases in traffic level. Many studies have identified distances of traffic effects on ungulates, primarily elk and deer. Early studies primarily focused on habitat selection by examination of pellet count densities (Perry & Overly 1976; Rost & Bailey 1979; Lyon 1979), or radio-telemetry locations within varying distances from roads (Witmer & deCalesta 1985). These early studies suggested that "habitat effectiveness" (the amount of habitat available to elk outside of the hunting season; Lyon and Christensen 1992:4) was reduced as road densities or road types (a surrogate for traffic levels) associated with different traffic levels (i.e., secondary, primary) increased. More recent studies (Rowland et al. 2000; Wisdom et al. 2005), have generally confirmed this pattern.

In this review we investigate various literature sources to examine the effect of traffic on ungulate-vehicle collisions, ungulate distribution along roadways and ungulate permeability across roads for various ungulate species. We also examine the traffic effect zone for ungulates associated with fluctuating traffic levels or different road types.

Methods

We searched various sources for literature examining the relationships of traffic levels, or road type and ungulates. We used only papers that examined traffic level or road type as a factor, or suggested that traffic had a potential impact on ungulates along roadways. We assumed road type (i.e. primary, secondary) was a classification of roads with different traffic levels. We identified the genera each study identified and whether traffic had an assumed effect. We then identified and placed each study into three categories: collisions, distribution, or permeability. The criteria for assigning studies to each category are as follows:

- *Collisions* – Studies that examined or suggested traffic levels (or road types) as a potential effect/no effect on ungulate-vehicle collision rates or trends.
- *Distribution* – Studies that examined or suggested traffic levels (or road types) as a potential effect/no effect on ungulate distributions in relationship to the roadway "habitat effectiveness", or habitat/resource selection.
- *Permeability* – Studies that examined or predicted traffic levels (or road types) as a potential effect/no effect on road crossings, road crossing behaviors, habitat fragmentation, or genetic isolation.

To examine the "traffic effect zone" for ungulate species we combined data across all literature sources that identified an actual distances where there was decreased distribution or habitat effectiveness. We determined four different road types: 1) primitive, 2) secondary, 3) primary, and 4) highway/interstate. We attempted to place studies in a given road type based on actual traffic levels, or descriptions given in the study. We determined the mean road effect zone for ungulates along each road type as well as all road types combined.

Results

Traffic Effects on Ungulates

We found that 71% of the 53 studies we examined incorporated traffic levels (or road type as a surrogate for traffic levels) associated with ungulate collisions, distributions, or habitat fragmentation, suggesting an effect of traffic level on ungulates. Interestingly, only 47% of the papers that examined deer showed a traffic effect while in contrast studies on some of the larger ungulates, such as elk and moose, were at 84% and 82% respectively. A further breakdown of our results are listed in table 1.

Table 1: Summary of literature identifying traffic levels effect on ungulates by Genera. Studies examining multiple species or effects counted more than once

Genus	**N**	**% Suggested traffic effects on Ungulate:**											
		Collisions			Distribution			Permeability			**Overall**		
		Yes	No	%	Yes	No	%	Yes	No	%	**Yes**	**No**	**%**
Moose	11	4	1	80%	5	0	100%	1	0	100%	**9**	**2**	**82%**
Pronghorn	5	NA	NA	NA	NA	NA	100%	5	0	100%	**5**	**0**	**100%**
Elk	23	2	2	50%	16	2	89%	3	0	100%	**21**	**4**	**84%**
Deer	17	6	6	50%	3	4	43%	NA	NA	NA	**9**	**10**	**47%**
Bighorn sheep	5	NA	NA	NA	NA	NA	NA	4	1	80%	**4**	**1**	**80%**
Caribou / Reindeer	4	0	2	0%	1	0	100%	1	0	100%	**2**	**2**	**50%**
Other	5	3	2	60%	NA	NA	NA	NA	NA	NA	**3**	**2**	**60%**

Of the studies that showed no effect of traffic, other factors such as ungulate populations, ungulate behavior, driver behavior, and landscape variables were generally considered to be reasons for increases in collisions.

Traffic Effect Zone for Ungulates

Thirteen studies identified either an actual or distance from the highway believed to be the effect zone for the ungulates they studied. The mean traffic effect zone for all road types was 381 m (SE +/-40m), when road type was examined individually the mean road effect zones increased with presumably increasing traffic levels. A breakdown of each road type shows an increasing trend of road effect distance as road type (traffic level) increased (Primitive = 200 m, Secondary = 304 m, Primary=374 m, Highway=425 m; fig. 1).

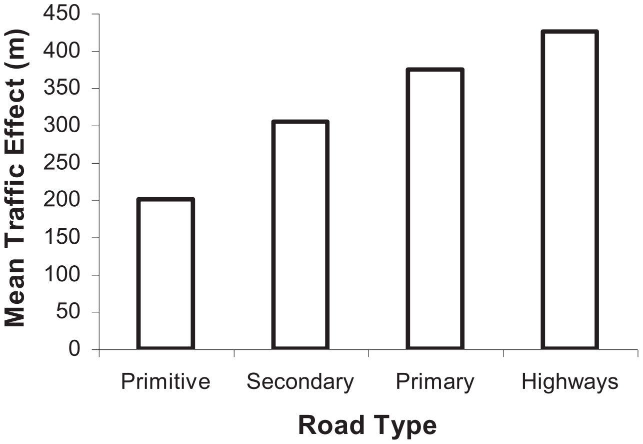

Figure 1. Mean traffic effect zone for all ungulates combined by road type, identified by 13 literature sources.

Effect of Fluctuating Traffic Levels on Elk: A Case Study in Arizona

(Summarized from Gagnon et al. 2007.)

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, confounding the effect of traffic with potential differences in habitat, resource type and availability, and human disturbance. In this study, we examined the effects of fluctuating hourly traffic levels on the distribution and movements of Rocky Mountain elk (*C. e. nelsonii*) in central Arizona along a relatively high traffic-volume highway (2004 AADT = 8,700).

Methods

We used 38,709 fixes collected from December 2003 through June 2006 from 44 elk (*Cervus elaphus*) fitted with Global Positioning System (GPS) collars and hourly traffic data recorded along 27 km of State Route 260 to determine how traffic volume affected elk distribution and highway crossings. We combined these locations and movement to traffic levels estimated using a permanent traffic counter programmed to record and transmit mean hourly traffic levels, speeds, vehicle type, and direction of travel. The traffic counter was installed in December 2003 at the center of the study area. No major roads branched off the highway along the length we studied, therefore we assumed that traffic volume recorded by the counter accurately represented levels present along that stretch of highway during any one hour interval.

To examine effects of fluctuating traffic levels on distribution, we examined how the proportion of elk locations at different distances from the highway varied with traffic level by calculating the percentage of locations in each 100-meter distance-band, out to a maximum of 600 m. We considered elk within 600 m of the highway as this adequately accounted for prior estimates of the road effect zone for elk. To avoid bias due to differences in sample size (number of locations) for individual elk, we used the proportion of fixes occurring in each distance band for each elk as the sample unit, rather than total fixes. We then calculated a mean proportion across all 44 elk at varying traffic levels out to 600 m.

To determine the effects of fluctuating hourly traffic on highway permeability we used a multiple logistic regression approach. We included other factors identified in the literature as that potentially influence elk movement near roads or are associated with higher elk-vehicle collision rates such as presence of riparian meadow habitat adjacent to roadways (Ward 1976, Dodd et al. 2006, 2007a, Manzo 2006). 2) Season (Groot Bruinderink and Hazebroek 1996, Gunson and Clevenger 2003, Dodd et al. 2006, 2007*b*). Sex (Marcum and Edge 1991, Gunson and Clevenger 2003, McCorquodale 2003, Dodd et al. 2006). 4) Time of night (Groot Bruinderink and Hazebroek 1996, Haikonen and Summala 2001, Dodd et al. 2006). Our binomial response variable was determined once an elk came within 250m of the highway as: 1) subsequent movement resulted in a crossing and 2) all other non-crossing movement. We converted the logistic regression models into calculated probabilities, and then graphed them for ease of interpretation

Results

Elk along State Route 260 showed a distinct shift in distribution associated with varying traffic levels. Elk were distributed closer to the road when traffic levels were less than 100 vehicles/ hr and shifted away from the road as these traffic levels increased (fig. 2)

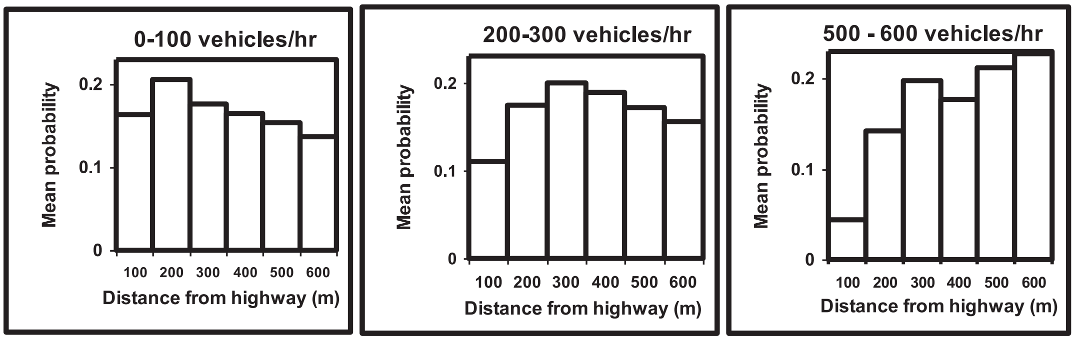

Figure 2. Probability of 44 occurring within a given distance to State Route 260 at selected traffic levels, 2003-2006, Arizona, USA. Modified from Gagnon et al. 2007*a*.

The most important factors in predicting a crossing selected through the logistic regression process included: 1) traffic level, 2) presence of riparian meadow, and 3) season. In this instance, time and sex were non-significant. The overall probability of a crossing decreased by approximately 20% when traffic levels increased to 1,500 vehicles/hr, however the magnitude of the effect of traffic on crossing probability was dependent on presence of riparian meadow as well as season (fig. 3)

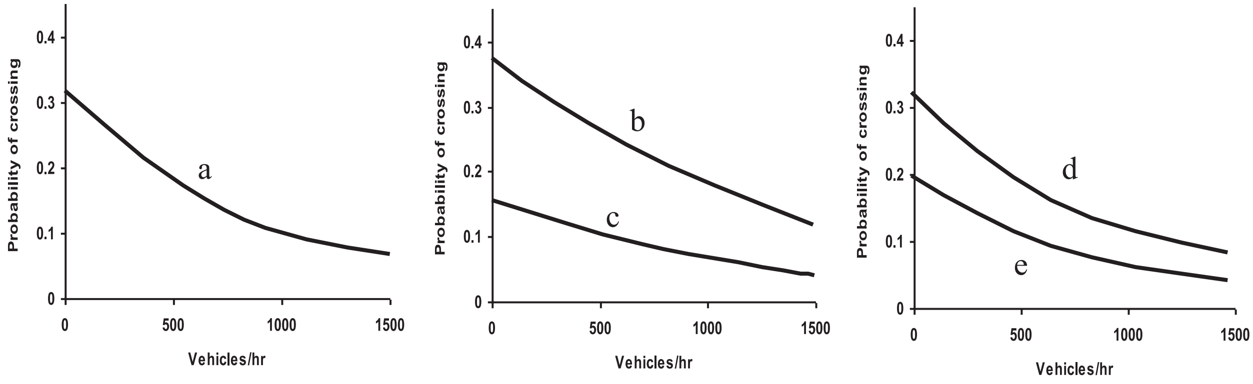

Figure 3. Probability of a successful highway crossing by 40 elk at increasing traffic levels: a) overall, b) with riparian meadow present, c) with riparian meadow absent, d) during non-migrational seasons, and e) during migration seasons. State Route 260, Arizona, USA, 2003-2006.

Discussion

Studies of lower volume roadways have documented that elk distribution shifted away from areas with roads (Perry & Overly 1976; Lyon 1979, 1983; Rost and Bailey 1979; Witmer & deCalesta 1985; Rowland et al. 2000; Wisdom et al. 2005), in our study these shifts were temporary, with elk returning to utilize areas near the highway at times of reduced traffic. Most previous studies that have indicated roads resulted in reduced “habitat effectiveness” (defined as “percentage of available habitat that is usable by elk outside the hunting season”; Lyon and Christensen 1992:4), examined roads with traffic levels less than 10% of those in our study. Our data suggests that the reduction in habitat effectiveness is a function of the reduced amount of time elk spend near highways as traffic levels increase rather than an overall reduction in population densities.

We also found that although there were overall decreases in crossing probabilities associated with increasing traffic levels, the magnitude of this effect was determined by presence of preferred foraging opportunities or dependent upon season. These findings indicate the overall drive for meeting survival requirements, such as food and water, or seasonal needs (migration, calving, mating, antler development) somewhat offset the overall negative effects of traffic on highway permeability, at least at the levels we studied. Lower traffic levels along highways that are not adjacent to preferred resources may inhibit elk movement at higher rates.

Ungulates and Traffic Level Thresholds

Iuell et al. (2003) and Trocme et al. (2003) report models that predict highways may become impermeable to many wildlife at 10,000 vehicles/day. We did not find this to be the case for elk along State Route 260 (Gagnon et al. 2007a) where traffic levels regularly reached 10,000 AADT. Not only are elk a highly mobile species that can make quick movements across the highway, on any given highway, traffic levels can vary seasonally, weekly and with time of day, allowing elk and many other animals to cross even high traffic-volume highways during periods of relatively low traffic flow.

Interstate 17 in northern Arizona appears to be reaching traffic levels that may significantly reduce the probability of a successful crossing through either road avoidance or elk-vehicle collisions (fig. 4). Traffic levels along this stretch of highway average around 17,000 AADT.

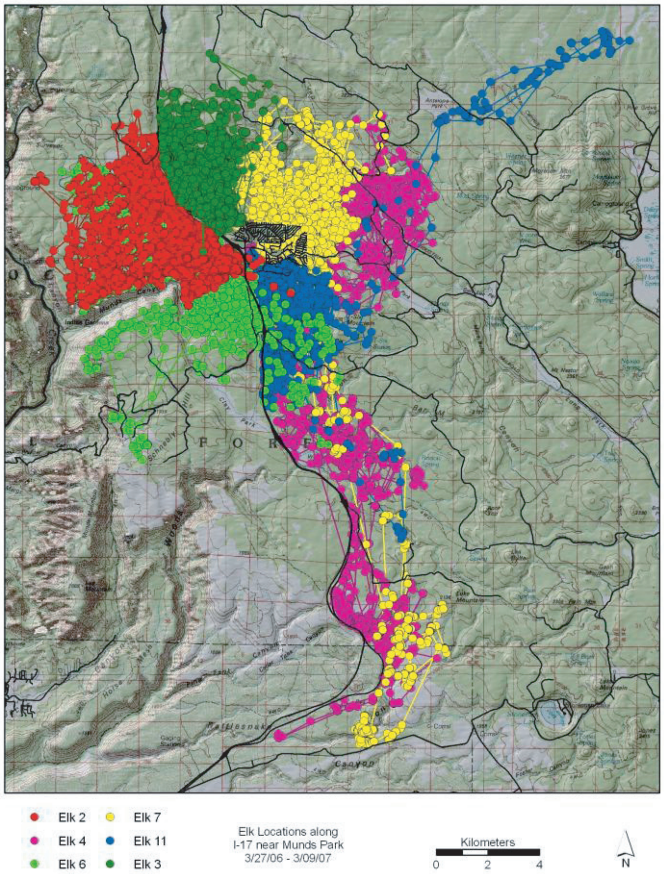

Figure 4. Preliminary movements of 6 elk along Interstate 17 (thick black line) in Arizona, USA, 2006-2007.

Within Species Traffic Level Tolerances

Individual animals within a species likely exhibit differences in thresholds to traffic levels. The individual variation among animals along the same stretch of highway may vary greatly. Gagnon (2006) reported differences among individual elk in regards to traffic levels during highway crossings. Dodd et al. (2007a) reported an average of >90 crossings/elk during that study, however some individuals crossed >400 times during the same study period indicating there were individuals that may have learned to cross at opportune times. One problem however is that animals that do cross more often still have a higher risk for interactions with vehicles. Dodd et al. (2006) found that collared elk that crossed the road >0.4 times/day were responsible for a majority of the collisions involving collared elk.

Because many ungulates exhibit a herding behavior, much of the behavior associated with highway crossings and non-crossings may be driven by the individual tolerances a lead animals such as a "lead cow" or "herd bull" in the case of elk. As a result, the sensitivity to traffic of a relatively small subset of the population may have important repercussions for the remainder of the herd. If those lead individuals readily cross the highway to obtain resources, the entire herd may herd may risk a higher potential of interaction with vehicles.

Wildlife of the same species in different geographical areas may also vary in their responses to traffic. Many studies have shown elk respond negatively to traffic even at relatively low levels along forest roads, as well highways. The elk along each of these road types may exhibit a "baseline" traffic tolerance in different geographical area; extreme deviations from these baseline traffic levels may elicit a response. For example, elk along low traffic level forest roads may react to a sudden increase in traffic levels. Likewise, elk along a highway that averages 10,000 vehicles/ day may develop a tolerance for these traffic levels and respond in a similar manner if traffic levels increases dramatically on a given day. Elk along each of these roads may adjust their baseline tolerance to traffic levels if there are increases or decreases in traffic along the route they inhabit.

Location and orientation of highways in different geographical areas may also differ in their effects of traffic on wildlife. The State Route 260 highway alignment was designed to run adjacent to riparian meadows and drainages for ease of construction. These areas are relatively scarce in the arid southwest and are of major importance to elk and other wildlife species in this area. Ungulate tolerances to traffic levels may be lower in areas where preferred resources are not adjacent to the highway, or where necessary resources are evenly distributed on both sides of a given highway, reducing the need to cross. Another important factor may be the orientation of the highway in relation to ungulate migration routes. State Route 260 runs east to west while the seasonal migration movements of elk in this area are north to south. Traffic levels along highways oriented parallel to migration routes may show a more profound barrier affect, as ungulates do not need to cross the highway during long range seasonal movements. This may be adequate for reducing ungulate-vehicle collisions, but does alleviate the problems of habitat effectiveness or habitat fragmentation and genetic isolation.

Between Species Traffic Level Tolerances

Differences between ungulate species and traffic levels they will tolerate are apparent according to previous studies. Deer appear to show the least response to traffic levels while many higher traffic roads are nearly impermeable to pronghorn.

One major factor of between species behavior associated with traffic may be the inherent nature of a species movements. Nocturnal species are likely to have greater crossing opportunities than diurnal species, due to the breaks in traffic during the middle of the night. For example, State Route 260 experiences traffic levels near 8,000 AADT, however traffic levels in the middle of the night regularly reach <50 vehicles/hr allowing crossings for many nocturnal species. A diurnal species along this same highway will endure much greater traffic levels, averaging close to 500 vehicles/hr during peak movement periods, thereby exacerbating the barrier effect of this road (fig. 5).

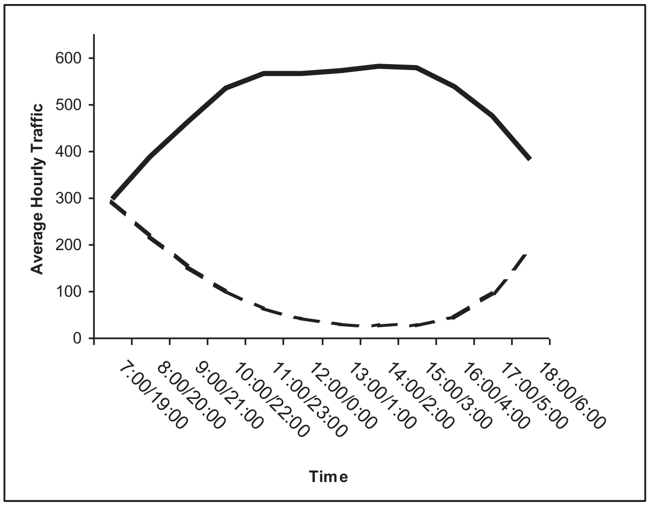

Figure 5. Traffic levels experienced by diurnal species (solid line; 0700-1800) versus those experienced by nocturnal species (dashed line;1900-0600) based on >6 million vehicles recorded in the State Route 260 Study Area from December 2003-June 2006, Arizona, USA.

Importance of Wildlife Passage Structures in Mitigating Traffic Effects

Properly designed wildlife crossing structures may help to alleviate the barrier effect of roadways while reducing wildlife-vehicle collisions. Several studies have evaluated wildlife crossing structure use (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, Gagnon et al. 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. 2007b, Gagnon et al. 2007b), most studies have not thoroughly examined the direct influence of variation in traffic and assume wildlife use of structures are related to the structural attributes of the underpasses. Although Singer and Dougherty (1985) documented decline in underpass use by mountain goats (*Oreamnos americanus*) when vehicles were present, 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."

Gagnon et al. (2007b) used video surveillance to simultaneously monitor elk crossing behavior associated with passing traffic (vehicles/min) during wildlife underpass use. Results from this study showed no overall effect of high traffic levels on elk use of wildlife underpasses. The only negative responses occurred at very low traffic levels, likely due to the dramatic change in ambient noise levels. Furthermore, data taken from the permanent traffic counter on State Route 260 showed a decrease in at-grade crossings as hourly traffic levels increased; while elk showed no real detrimental response to the same hourly traffic levels during below-grade crossings (fig. 6). These findings along with those of Dodd et al. (2007c) showed an overall increase in permeability following the completion of wildlife crossing structures and properly placed funnel fencing. The combined overall findings along State Route 260 indicate that properly designed and located wildlife underpasses, combined with adequate funnel fencing helped to overcome the potential negative effects of highway traffic on both permeability and collisions for elk in this area.

Gagnon et al. (2007a) showed that elk along State Route 260 moved farther away as traffic levels increased, suggesting that overall approach rates at underpasses may be lower at higher traffic levels. If so, high traffic may lengthen the amount time animals require locating and habituating 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" traffic creates. These modifications could also reduce the sound of vehicles passing directly overhead, particularly semis, thereby reducing the probability that elk will retreat from underpasses and attempt to cross the highway at other locations where they could be a danger to motorists.

Although design and placement of crossing structures appear to far outweigh the negative effects of traffic for elk, more research is needed to determine if other wildlife respond negatively to passing traffic during use of wildlife crossings. Although elk showed very minimal response to traffic during below grade crossings, other wildlife may not cross through structures if traffic levels are too high. American pronghorn may be a good example of this; the ability to promote pronghorn passage with such structures has been limited to date, as is our knowledge (Sawyer and Rudd 2005). Though Plumb et al. (2003) documented 70 crossings by pronghorn at a concrete box-culvert underpass in Wyoming (81% in a single crossing), pronghorn overall exhibited reluctance to use the structure and most of the crossing animals accompanied mule deer through the underpass. As crossing structures for barrier sensitive species, such as pronghorn, are implemented throughout the world, it is important to understand their responses to traffic. Does the visual "fence" created by passing traffic reduce the probability of a species even approaching a given crossing structure? Once a given species attempts to use a crossing structure do vehicles elicit a negative response leading to unsuccessful crossings?

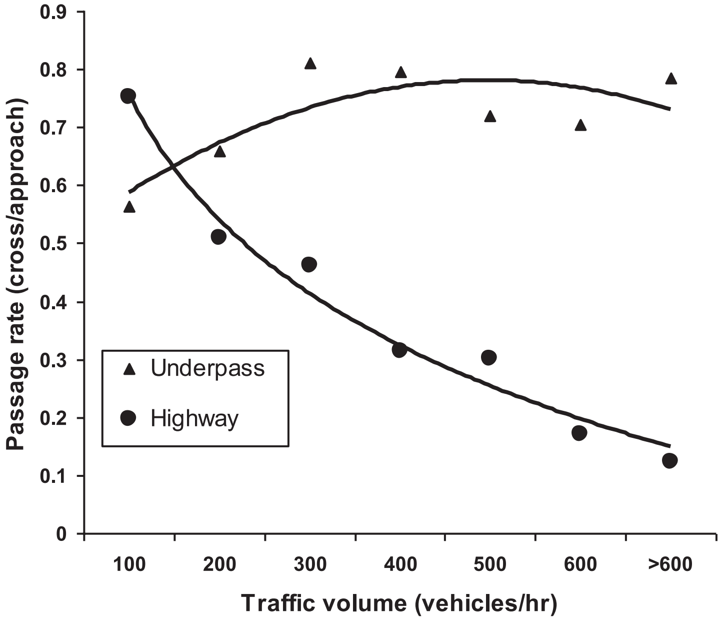

Figure 6. Elk passage rates at grade (highway) and below grade (underpass) at varying traffic levels during identical time periods along State Rout 260, 2003-2006, Arizona, USA.

Current Research in Arizona

Although studies have examined fluctuating traffic levels on ungulate distribution, most of these were along very low traffic roads (Witmer and deCalesta 1986, Wisdom et al. 2005, Rost and Bailey 1979), very few of them adequately examined distributions along high speed, high traffic roads such as highways and interstates. These types of roads are increasing throughout the world, and are not only a safety issue to motorists and ungulates but also an increasing problem for resource selection and habitat fragmentation, potentially leading to genetic isolation. Our better understanding of ungulate-distributions and movements associated with various traffic levels and other factors may help us find ways to mitigate the effects of highways on wildlife.

Currently, Arizona has four separate wildlife-highway interaction projects along four different highways tied to hourly traffic counts. We are studying traffic effects on elk (State Routes 260 and 64, Interstate 17), Coues' white-tailed deer (State Route 260), mule deer (State Route 64), and pronghorn (US Highway 89 and State Route 64). These projects include highways with varying traffic levels. This research will add to the wildlife-highway "toolbox" by providing a better understanding of how fluctuating traffic levels affect different species of wildlife in different locations.

References

Allen R.E. , and D. R. McCullough. 1976. Deer car accidents in southern Michigan. *Journal of Wildlife Management*. 40:317:325

Bashore, T. L., Tzilkowski, W. M., Bellis, ED. 1985. Analysis of deer-vehicle collision sites in Pennsylvania. *Journal of Wildlife Management*, 49(3):769-776

Beier, P. and S. Loe. 1992. A checklist for evaluating impacts to wildlife movement corridors. *Wildlife Society Bulletin* 20:434-440.

Beier, P. 1995.Dispersal of juvenile cougars in fragmented habitat. *Journal of Wildlife Management* 59:228-237.

Bellis, E. D., and H. B. Graves. 1978. Highway fences as deterrents to vehicle-deer collisions. *Transportation Research Record* 674: 53-58.

Groot Bruinderink, G. W. T. A, and E. Hazebroek. 1996. Ungulate traffic collisions in Europe. *Conservation Biology* 10:1059-1067.

Hanski, I., and M. E. Gilpin. 1997. Metapopulation biology. Academic Press, New York, New York, USA.

Iuell, B., Becker, G. J., Cuperus, R., Dufek, J., Fry, G., Hicks, C., Hlavac., V. Keller, V.B., Rosell, C., Sangwine, T., Torslov, N., Wandall, and B. le Maire. 2003. Cost 341- wildlife and traffic. A European handbook for identifying conflicts and designing solutions. Office for Official Publications of the European Communities, Luxembourg.

Clevenger, A. P. and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology* 14:47-56.

Clevenger, A. P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation* 121:453–464

Brudin, C.O. 2003. Wildlife use of existing culverts and bridges in north central Pennsylvania. ICOET 2003 Proceedings

Carbaugh, B., J. P. Vaughan, E. D. Bellis, and H. B. Graves. 1975. Distribution and activity of white-tailed deer along an interstate highway. *Journal of Wildlife Management*. 39:570-581.

Case, R.M. 1978. Interstate highway road killed animals; a data source for biologists. *Wildlife Society Bulletin* 6:8-13.

Conover M. R., W. C. Pitt, K. Kessler, T. J. DuBow, and W. A. Sanborn. 1995. Review of human injuries, illness, and economic losses caused by wildlife in the United states. *Wildlife Society Bulletin*, 23: 407-414.

Danielson, B. J. and M. W. Hubbard, 1998. Final report: a literature review for assessing the status of current methods of reducing deer-vehicle collisions. Iowa Department of Transportation, Ames, USA.

Davis, W. B. 1939. Mortality of wildlife on a Texas highway. *Journal of Wildlife Management*. 4:90-91.

Dickerson, L. M. 1939. The problem of wildlife destruction by automobile traffic. *Journal of Wildlife Management*. 3:104-116.

Dodd, N. L., J. W. Gagnon, S. Boe, and R. E. Schweinsburg. 2006. Characteristics of elk-vehicle collisions and comparison to GPS-determined highway crossing patterns. Pages 461-477 in C. L. Irwin, P. Garrett, and K.P. McDermott, technical coordinators. *Proceedings of the 2005 International Conference on Ecology and Transportation*., North Carolina Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Dodd, N. L., J. W. Gagnon, A. L. Manzo, and R. E. Schweinsburg. 2007a. Application of video surveillance to assess wildlife use of highway underpasses in Arizona. *Journal of Wildlife Management* 70:in press.

Dodd, N. L., J. W. Gagnon, S. Boe, and R. E. Schweinsburg. 2007b. Assessment of elk highway permeability using Global Positioning System telemetry. *Journal of Wildlife Management* 71:in press.

Dodd, N. L., J. W. Gagnon, S. Boe, and R. E. Schweinsburg. 2007c.Role of fencing in promoting wildlife underpass use and highway permeability. Pages xxx-xxx in *Proceedings of the 2007 International Conference on Ecology and Transportation*. North Carolina Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Epps, C. W.,P. J. Palsboll, J. D. Wehausen, G. K. Roderick, R. R. Ramry II, and D. R. McCullough. 2005.Highways block gene flow and cause rapid decline in genetic diversity od desert bighorn sheep. *Ecology Letters*. 8:1029-1038.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road ecology: science and solutions*. Island Press. Washington, DC, USA.

Foster, M. L., and S. R. Humphrey. 1995. Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin* 23:95-100.

Gagnon, J. W. 2006. Effect of traffic on elk distribution, highway crossings, and wildlife underpass use in Arizona. Thesis, Northern Arizona University, Flagstaff, Arizona, USA.

Gagnon, J. W., N. L. Dodd, R. Schweinsburg, and A.L. Manzo. 2006. Comparison of wildlife underpass usage along State Route 260 in Central Arizona. Pages 534-544 in C. L. Irwin, P. Garrett, and K.P. McDermott, technical coordinators. *Proceedings of the International Conference on Ecology and Transportation., North Carolina Center for Transportation and the Environment*, North Carolina State University, Raleigh.

Gagnon, J. W., T. C. Theimer, N. L. Dodd, R. E. Schweinsburg. 2007a. Traffic volume alters elk distribution and highway crossings in Arizona. *Journal of Wildlife Management*. 71:in press.

Gagnon, J. W., T. C. Theimer, N. L. Dodd, A. L. Manzo, and R. E. Schweinsburg. 2007b. Effects of traffic volume and type on elk use of wildlife highway underpasses in central Arizona. *Journal of Wildlife Management*. 71:in press.

Gloyne, C. G., and A. P. Clevenger. 2001. Cougar Puma concolor use of wildlife crossing structures on the Trans-Canada highway in Banff National Park, Alberta. *Wildlife Biology* 7:117-124.

Gordon, K., and S. Anderson. 2003. Mule deer use of underpasses in western and southeastern Wyoming. Pages 309-318 in C. L. Irwin, P. Garrett, and K.P. McDermott, technical coordinators. *Proceedings of the International Conference on Ecology and Transportation*, North Carolina Center for Transportation and the Environment, North Carolina State University, Raleigh.

Gunson, K. E., and A. P. Clevenger. 2003. Large animal-vehicle collisions in the central Canadian Rocky Mountains: patterns and characteristics. Pages 355-366 in C. L. Irwin, P. Garrett, and K.P. McDermott, technical coordinators. *Proceedings of the International Conference on Ecology and Transportation, North Carolina Center for Transportation and the Environment*, North Carolina State University, Raleigh, USA.

Haikonen, H., H. Summala. 2001. Deer-vehicle crashes, extensive peak at 1 hour after sunset. *American Journal of Preventive Mediceine*. 21:209-213.

Haugen, A. O. 1944. Highway mortality of wildlife in souther Michigan. *Journal of Mammology*. 25 :177-183.

Hershey, T.J., and T.A. Leege. 1976. Influences of logging on elk summer range in north-central Idaho. Pages 73-80 in Hieb, S.R. (ed.) Proceedings of the Elk-Logging-Roads Symposium. Moscow, Idaho. December 16-17, 1975. Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow. 142 pp.

Hourdequin M. 2000. Introduction special section: Ecological effects of roads. *Conservation Biology*. 14:16-17.

Lyon, L. J. 1979. Habitat effectiveness for elk as influenced by roads and cover. *Journal of Forestry* 79:658-660.

Lyon, L. J. 1983. Road density models for describing habitat effectiveness for elk. *Journal of Forestry* 81:592-595.

Lyon, L. J., and A. G. Christensen. 2002. Elk and land management. In North American elk: ecology and management, eds. D. E. Toweill and J. W. Thomas, 557-581. Washington, DC: Smithsonian Institution Press.

Manzo, A. L. 2006. An ecological analysis of environmental parameters influencing Rocky Mountain elk crossings of an Arizona highway. Thesis, Northern Arizona University, Flagstaff, USA.

Marcum, C. L., and W. D. Edge. 1991. Sexual differences in distribution of elk relative to roads and logged areas in Montana. In Proceedings Elk Vulnerability Symposium, eds. A. G. Christensen, L. J. Lyon, and T. N. Lonner, 142-148. Bozeman: Montana State University.

McCaffery, K. R. 1973. Road-kills show trends in Wisconsin deer populations. *Journal of Wildlife Management*. 37:212-216.

McCorquodale, S. M. 2003. Sex-specific movements and habitat use by elk in the Cascade Range of Washington. *Journal of Wildlife Management* 67:729-741.

Ng, S. J., J. W. Dole, R. M. Sauvajot, S. P. D. Riley, and T. J. Valone. 2004. Use of highway underpasses by wildlife in southern California. *Biological Conservation* 115:499-507.

Noss, R. F., A. Y. Cooperrider. 1994. Saving nature's legacy: Protecting and restoring biodiversity. Island Press, Washington D.C. 1994: p. 416.

Perry, C., and R. Overly. 1976. Impacts of roads on big game distributions in portions of the Blue Mountains of Washington. Pages 62-68 in Hieb, S.R. (ed.) Proceedings of the Elk-Logging-Roads Symposium. Moscow, Idaho. December 16-17, 1975. Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow. 142 pp.

Plumb, R. E., K. M. Gordon, and S. H. Anderson. 2003. Pronghorn use of a wildlife underpass. *Wildlife Society Bulletin* 31:1244-1245.

Reed, D. F., T. N. Woodard, and T. M. Pojar. 1975. Behavioral response of mule deer to a highway underpass. *Journal of Wildlife Management* 39:361-367.

Reed, D. F. 1981. Mule deer behavior at a highway underpass. *Journal of Wildlife Management* 45:542-543.

Reilly, R. E., and H. G. Green. 1974. Deer Mortality on a Michigan Interstate Highway. *Journal of Wildlife Management*, 38:16-19

Romin L. A., and J. A. Bissonette. 1996. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle Reservoir, Utah. *Great Basin Naturalist*. 56:1-11.

Rost, G. R., and J. A. Bailey. 1979. Distribution of mule deer and elk in relation to roads. *Journal of Wildlife Management* 43:634-641.

Rowland, M. M., M. J. Wisdom, B. K. Johnson, and J. G. Kie. 2000. Elk distribution and modeling in relation to roads. *Journal of Wildlife Management* 64:672-684.

Ruediger, W. C., K. Wall and R. Wall. 2006. Effects of highways on elk (Cervus elaphus) habitat in the western United States and proposed mitigation approaches. Pages 269-278 in C. L. Irwin, P. Garrett, and K.P. McDermott, technical coordinators. *Proceedings of the International Conference on Ecology and Transportation*., North Carolina Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Russel, H. N. & D. Amadon 1938: A note on highway mortality. *Wilson Bulletin* 50: 205-206.

Schwabe, K. A., and P. W. Schuhmann. 2002. Deer-vehicle collisions and deer value: an analysis of competing literatures. *Wildlife Society Bulletin* 30:609-615.

Seiler, A. 2004. Trends and spatial patterns in ungulate – vehicle collisions in Sweden. *Wildlife Biology* 10: 301-313.

Servheen, C., Shoemaker, R. and L. Lawrence. 2003. A sampling of wildlife use in relation to structure variables for bridges and culverts under I-90 between Alberton and St. Regis, Montana. Pages 331-341 in C. L. Irwin, P. Garrett, and K.P. McDermott, technical coordinators. *Proceedings of the International Conference on Ecology and Transportation*, North Carolina Center for Transportation and the Environment, North Carolina State University, Raleigh.

Singer, F. J. and J. L. Doherty. 1985. Managing mountain goats at a highway crossing. *Wildlife Society Bulletin* 13:469-477.

Sips, H. J. J., G. F. J. Smit, and G. Veenbaas. 2002. Applicability of automatic video recording near fauna passages. Road and Hydraulic Engineering Division Report No. DWW-2002-141.

Starrett, W. C. 1938. Highway casualties in Central Illinois during 1937. *Wilson Bulletin* 50 (3):193-196.

Stoner, D. 1925. The toll of the carmobile. *Science* 61 (1568): 56-57.

Stoner, D. 1936. Wildlife casualties on the highways *Wilson Bulletin* 48: 276-283.

Sawyer H., and B. Rudd. 2005. Pronghorn roadway crossings: A review of available information and potential options.

Trocme, M. S. Cahill, J. G. de Vries, H. Farrall, L. G. Folkeson, C. Hichks, and J. Peymen (Eds.) 2003. COST 341 – Habitat fragmentation due to transportation infrastructure: the European review. Office for Official Publications of the European Communities, Luxembourg.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18-30.

Ward, A.L. 1976. Elk behavior in relation to timber harvest operations and traffic on the Medicine Bow Range in south-central Wyoming. Pages 32-43, in S.R. Hieb and J.M. Peak, editors, Proceedings of the Elk-Logging-roads Symposium. Moscow, Idaho. December 16-17, 1975. Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow, USA.

Ward, A.L. 1982. Mule deer behavior in relation to fencing and underpasses on Interstate 80 in Wyoming. *Transportation Research Record* 859:8-13.

Warren, E. R. 1936: Casualties among animals on mountain roads. *Science* 83 (2140): 14.

Warren, E. R. 1936: Mountain road casualties among animals in Colorado. *Science* 84 (2187): 485.

Wisdom, M. J., N. J. Cimon, B. K. Johnson, E. O. Garton, and J. W. Thomas. 2005. Spatial Partitioning by Mule Deer and Elk in Relation to Traffic. Pages 53-66 in Wisdom, M. J., technical editor, The Starkey Project: a synthesis of long-term studies of elk and mule deer. Reprinted from the 2004 Transactions of the North American Wildlife and Natural Resources Conference, Alliance Communications Group, Lawrence, Kansas, USA.

Witmer, G. W., and deCalesta. 1985. Effect of forest roads on habitat use by Roosevelt elk. *Northwest Science*. 59:122-125.