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Original article

An evaluation of a mitigation strategy for deer-vehicle collisions

John A. Bissonette & Silvia Rosa

High mule deer *Odocoileus hemionus* mortality in southwestern Utah led to the establishment of a mitigation strategy with two major objectives: 1) reduction of wildlife-vehicle collisions and 2) restoration of landscape connectivity to facilitate wildlife movement across the roaded landscape. During our study, we assessed the effectiveness of the mitigation measures in reducing mule deer mortality in the following ways: 1) we compared the number of deer-vehicle collisions in the newly fenced area with a control area without fencing; 2) we analyzed the 'end-of-the-fence' problem, defined here as increased mortality of mule deer at the ends of the 2.4-m high exclusion fences; and 3) we evaluated the frequency of animal crossings of the new underpasses using remotely-sensed cameras and compared them with crossing frequency rates for a 20-year-old control underpass. We compared six years of pre-construction mortality (during 1998-2003) with two years of post-construction data on mortality (during 2005-2006) and found a 98.5% decline in deer mortalities in the treatment (i.e. fenced, jump-outs and underpasses) vs a 2.9% decline in the control (i.e. no fences, no jump-outs and no underpasses). We detected no end-of-the-fence problems related to deer mortality. Migratory movements during fall and spring were clearly reflected in the use of underpass. Overall results demonstrated that the mitigation strategy was effective and reduced the number of deer-vehicle accidents, while allowing wildlife movement across the landscape.

Key words: crossing structures, end-of-the-fence problem, escape ramps, exclusion fencing, landscape connectivity, mitigation, mortality, mule deer, Odocoileus hemionus, road-kill, underpasses, wildlife-vehicle collisions

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The increase in animal-vehicle collisions worldwide is a reflection of the increased anthropogenic transformation of the landscape. Current estimates of the total landscape transformed by human influences (e.g. forest removal, agricultural activities including crop planting and livestock grazing) range from 39 to 50% of the total earth surface (Vitousek et al. 1997). When Riitters & Wickham (2003) measured the proximity of different land-cover types in the U.S. to the proximity of a road using nine distance classes, they found that the proportion of land area within a defined distance to a road increased rapidly with distance. Of all land area in the U.S., 50% was within 382 m of a road; only 18% was > 1,000 m of a road. Clearly, as road density increases as a function of human development, so does mean animal proximity to roads. The U.S. has a mean road density of 0.75 km/km^2 with concomitant habitat loss, animal mortality, isolation and barrier effects (Jaeger & Fahrig 2004, Jaeger et al. 2005, Row et al. 2007).

As road networks have expanded, so have traffic volumes, which have been linked to deer mortality (Gunson et al. 2006). In the U.S., traffic volumes in 1998 totaled 2,625,367 $\times 10^6$ vehicle miles; in 2007 traffic volume had increased to 3,003,218 $\times 10^6$, $\sim$ a 14.4 % increase (Available at: http://www.fhwa.dot.gov/ohim/tvtw/07dectvt/page2.htm). For Utah, annual vehicle-miles traveled (VMT) in 2007 totaled 26.8 billion miles (Available at: http://www.udot.utah.gov/main/f?p=100:pg:0::::V,T:,530), an increase of ~ 26.4 % from the 1998 VMT of 21.2 billion miles.

One of the most evident effects of the increased traffic volume on wildlife is the increased number of wildlife-vehicle collisions (Bissonette & Cramer 2008, McCollister & van Manen 2010). Even though Skölving (1987), Berthoud (1987) and Seiler (2005) suggested that high traffic volumes tended to cause road avoidance by animals; nevertheless, nationwide estimates of 1.1 million deer-vehicle collisions (DVCs) during the period between 1 July 2008 and 30 June 2009, or ~ 21,150/week (State Farm Insurance Company® 2009), reveal the growing importance of the problem in the U.S. When seven years of data were recalculated in 3-year time steps to smoothen extraordinary high or low years of DVCs, 2006-2009 showed a 15.3% increase over the previous three years. The comparable figure for Utah is 25%. State Farm® estimated that the likelihood of any vehicle colliding with a deer in 2010 was 1:208 for the U.S. and 1:404 for Utah. In the Intermountain West, wildlife-vehicle collisions primarily involve ungulates in general and mule deer *Odocoileus hemionus* in particular. In Utah, mule deer numbers have declined generally over the past several decades with current estimates of < 300,000 animals, from an estimated 500,000 deer in the 1950s (Utah Department Wildlife Resources 2009).

In 2003, to increase driver's safety, reduce deer mortality and provide deer access to their traditional seasonal ranges across I-15, three agencies (Utah Division of Wildlife Resources (UDWR), Utah Department of Transportation (UDOT) and the Bureau of Land Management (BLM)) jointly created a mitigation strategy that included three integrated actions: 1) construction of two wildlife underpasses, 2) construction of exclusion fencing and 3) installation of 1-way earthen escape ramps. The underpasses were constructed to allow below-grade road crossing, thereby reducing the putative barrier effect created by wildlife exclusion fencing and the road (Foster & Humphrey 1995, Bruinderink & Hazebroek 1996, Jaeger & Fahrig 2004). Exclusion fencing is seldom, if ever, 100% effective, even with continued maintenance (Putman 1997), so earthen 1-way escape ramps were constructed being spaced ½ mile apart to allow deer that accessed the fenced right-of-way (ROW) an escape route. The overall objectives of the mitigation were to improve driver safety, reduce the number of DVCs and to restore landscape connectivity for migrating deer.

For the mitigation strategy to be considered effective and because formally established criteria were unavailable, we established three *a priori* criteria. First, DVCs on the treatment section needed to be reduced by ≥ 70%. We chose this threshold based on studies of mule deer in northern Utah (Lehnert 1996, Lehnert et al. 2008) and reductions in mortality observed in successful mitigations strategies elsewhere (McDonald 1991, Clevenger et al. 2001). Second, there should not be an increase in DVCs at the ends of the exclusion fencing (i.e. the so-called 'end-of-the-fence' problem; Bellis & Graves 1971, Clevenger et al. 2001). Third, because of habituation, there should be an increase in underpass use by deer, and use should increase with time (Ward 1982).

We conducted a study using six years of pre-construction data (1998-2003) and three years of post-construction data (2004-2006). We examined if fences and escape-ramps jointly reduced deer mortality on the road, and if underpasses were used by mule deer during seasonal migrations. We evaluated the prediction that the average change in mortality in the treatment area was equal to or lower than in a control area.

Study area

Our study area was located on I-15 in southern Utah, between the I-15 and I-70 interchange at Mile Post (MP) 132 and MP 112 just north of Beaver (Fig. 1). This area was paired with a control area located between MP 137 and MP 144. I-15 is a four-lane divided paved interstate highway. These stretches of road historically have had heavy deer mortality (Kassar 2005). In this area, deer traditionally migrated east to summer ranges at higher elevations, and west to winter ranges at lower elevations, frequently crossing I-15. The upgrade of this road to an Interstate in the 1960s and 1970s blocked the traditional migratory route, causing considerable deer mortality (B. Bonebrake, Utah Division of Wildlife Resources, pers. comm. and unpubl. data), and coupled with heavy traffic volumes disrupted the migratory routes. Annual Average Daily Traffic (AADT) for the study site in 1998 was 12,835 vehicles/day; in 2009 it was 16,680 vehicles/day, an increase of 30% (Available at: http://www.udot.utah.gov). Despite the high kill, deer continued to cross the highway during the spring and autumn migrations and as a consequence, a 9.6 km stretch of road (MP 121-126) still recorded heavy mortality. The surrounding habitat included patches of big sagebrush *Artemisia tridentata*, pinyon pine *Pinus edulis*, juniper *Juniperus osteosperma*, agricultural

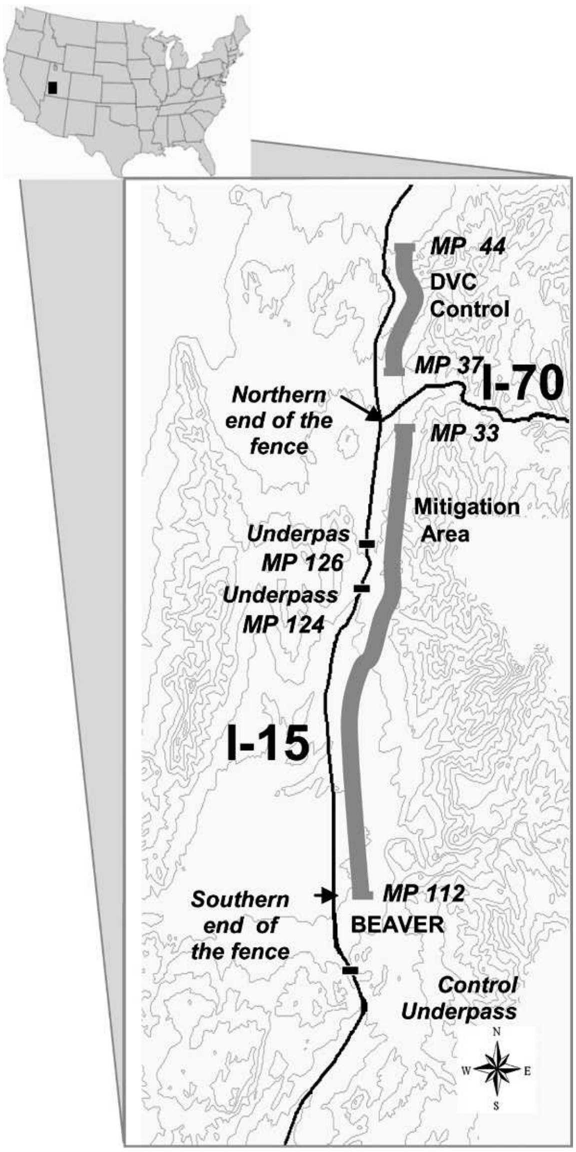

Figure 1. Study area location in southern Utah, USA, showing the location of deer-vehicle collision (DVC) control area, mitigation area, monitored underpasses and fence extension in the study area.

fields and small towns. The posted speed limit on I-15 in the area was 120.7 km/hour (75 mph).

Mitigation strategy description

Mitigation construction started in spring 2004 and ended in autumn 2004. Construction crews erected a 2.44-m (eight feet) deer-exclusion fence on both sides of the road during summer 2004 from MP 112 to 132. Additional fencing extended the northern end of the fence to MP 133 during the summer of 2005 to prevent deer from accessing the highway via the I-15 - I-70 interchange. Construction crews installed earthen escape ramps (N = 64) throughout the 32.2 km stretch of the study area at approximately 0.81 km (0.5 mile) intervals. Two underpasses specifically designed for wildlife were constructed and placed at the hotspot areas of greatest kill according to prior data on mortality of deer. Underpass 1 (UP1) was constructed at MP 126, and Underpass 2 (UP2) at MP 124 (see Fig. 1). Both structures were oval-shaped tunnels, made of corrugated metal, with large open middle areas. UP 1 (Fig. 2A) had an openness-ratio score of 3.68 (6.55 m height x 11.13 m width/19.82 m length) in each tunnel section and incorporated a dirt road with recreational traffic. UP2 (Fig. 2B) had an openness-ratio score of 1.62 (4.23 m height x 8.12 m width/21.23 m length) in each tunnel section and was designed solely for wildlife use. Foster & Humphrey (1995) and Clevenger & Waltho (2005) suggested that crossings with higher openness ratios were more likely to be used by large mammals. UP 2 followed the topography of Wildcat Creek (but was not impacted by the stream) and hence the two parts of the underpass were not aligned (see Fig. 2B). We baited the new structures irregularly with alfalfa hay, apples and salt blocks placed near the entrances at the beginning of the migrations in spring and fall to encourage use by deer.

Method

Mitigation monitoring

Deer-vehicle collisions

To assess the joint effects of fencing and escape ramps in reducing mortality of mule deer on the road, we analyzed carcass-removal counts before and after mitigation. Data from carcass-removal surveys from UDOT databases were available. Contract personnel removed deer carcasses from the road in an average of four times per month from 1998 to 2006. To distinguish mitigation effects from the usual yearly fluctuation of road mortality, we monitored a similar control area located north of the study area (MP 137-144; see Fig. 1). This area had high mortality, but no exclusion fencing. We used a Before-After-Control-Impact (BACI) approach to assess if variation on road mortality was related to the intervention (Eberhardt 1976, Green 1979). By itself, a drop in mortality on the treatment area would not necessarily be a consequence of the mitigation, but a higher proportional decrease of mortality when compared

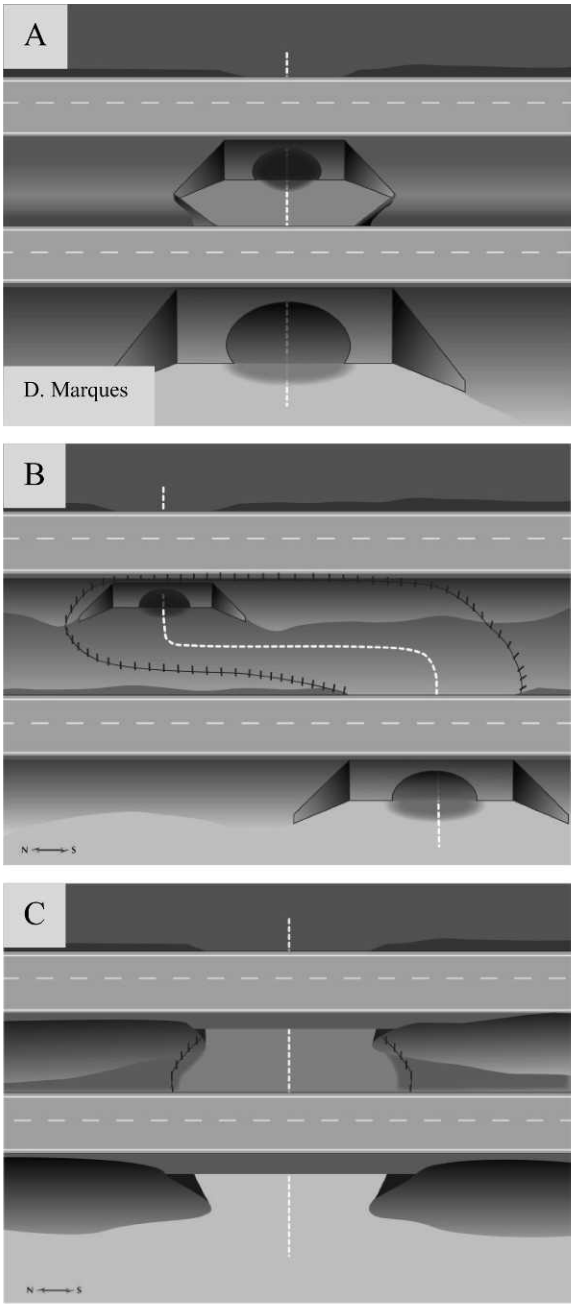

Figure 2. Schematic representation of underpasses monitored in the study area on I-15, southern Utah, USA. (A: UP1; B: UP2, C: Control UP). Images ©Diana Marques (www.dianamarques.com).

with a control area would reflect a successful mitigation. We compared the annual DVC average for six years before and two years after construction. For each year, we estimated difference in mortality counts between control and treatment areas by using T-tests, and corrected for multiple comparisons. We compared mortality before and after mitigation for the duration of the study, averaged by year and during autumn (October-January) and spring migrations (April-July), and we assessed whether the mitigation was effective in reducing mortality at the hotspot area (MP 120-126) by comparing annual averages of deer mortality before and after the mitigation. To test if end-of-the-fence problems existed (mortality that occurred within 2.4 km (1.5 miles) at either end of the fence), we compared annual deer mortality before and after the mitigation at the northern (MP 131-134) and the southern (MP 111-113) ends of the fence.

Underpass use

We monitored a 20-year-old control underpass (Control UP) to compare mule deer use between new and established structures. The Control UP was located south of the study area (MP 103) in a similar mule deer migration area (see Fig. 1). The Control UP (see Fig. 2C) was comprised of two double-span bridges with an openness-ratio score of 4.43 each (4.12 m height × 21.49 m width/20 m length) and a large open median area. This Control UP was in a more remote area, did not have a dirt road under it and an exclusion fence was present. Mule deer and elk *Cervus elaphus* use had been previously reported.

We placed Reconyx® cameras (digital, triggered by motion and heat, with infrared illumination) inside the median of each underpass to record animal crossings. We chose camera placement to assure approximately equal photo capture probabilities in all the structures and camouflaged them by mounting inside locked urban electric boxes to reduce the probability of damage or theft. We equipped cameras with 512 Mb memory cards, which were examined on average twice each month from October 2004 to August 2006. We set the cameras for maximum sensitivity, with a 2-second lag between triggers and one picture/trigger. We sampled four migration periods (autumn: October - November 2004; spring: April - June 2005; autumn: September - November 2005; spring: April - June 2006).

We used camera data to: 1) characterize overall use of the structures and 2) estimate deer crossing frequency and temporal variation. We categorized all photos into classes (mule deer, humans, cattle and other wildlife). We used photos taken of mule deer to estimate use and changes with time. Because all cameras were fully functional for > 90% of the monitoring period (i.e. a total of 678 days), the results constitute a census rather than sample data. As a result, null hypotheses and significance testing have little theoretical interpretation (Berger 1985, Gill 2001). Thus, analysis of underpass use and changes over time are primarily descriptive, using summary statistics and simple χ^2 tests. Throughout this paper, we employed simple statistics, following the advice of Guthery (2008) and Thompson (2010).

Generally speaking, mule deer are not individually identifiable by unique external characteristics (e.g. pelage markings). This impeded the estimation of the exact number of different individuals using the structures and the frequency at which the same individuals crossed. Therefore, we only counted the total number of crossings detected. We also noted direction of the crossings: west to winter ranges and east to summer ranges. We calculated the net number of crossings from the difference between crossings recorded in each direction. We used net crossings to monitor changes in movement in either direction through time. This allowed the detection of migration periods as well as changes in use of new underpasses.

We used SPSS 15.0.1 (2006) for all analyses. Animal welfare protocols were followed according to Utah State University IACUC Protocol Number 1139. Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

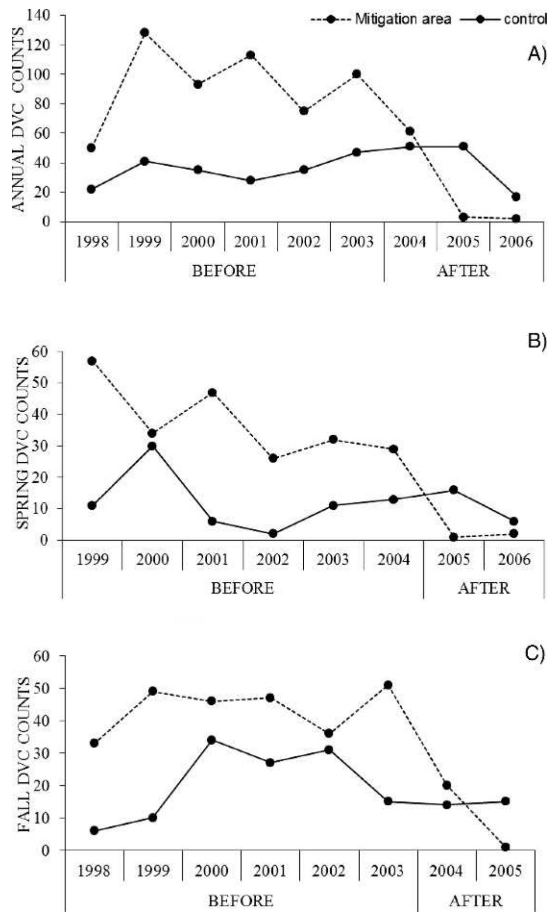

Figure 3. Deer-vehicle collision (DVC) counts in control and mitigated areas on an annual basis (A), during spring (B) and fall (C). The dashed line represents mitigation strategy implementation. Data from UDOT deer carcass removals on I-15 in southern Utah, USA.

Results

Deer-vehicle collisions

The BACI analyses of carcass removal data indicated that reduction in DVCs was related to the mitigation and not to stochastic annual oscillations in mortality in the study area. To be conservative, we included 2004 in the post-treatment analysis, even though the mitigation was not completed until late in the year. We documented a significant decrease in annual DVC levels ($t = 4.244$, $P = 0.004$, $df = 7$) that corresponded to a 77% reduction in mortality after the mitigation (Fig. 3A). We calculated a Cohen's d of 2.32 with an effect size $r = 0.757$. DVC levels in spring decreased ($t = 2.903$, $P = 0.027$, $df = 7$) corresponding to a 96% mitigation-induced reduction in mortality (Fig. 3B). Finally, DVC levels in autumn were similarly reduced ($t = 2.463$, $P = 0.049$, $df = 7$) to levels that corresponded to 76% of the original mortality (Fig. 3C). If we consider 2004 as a transition year and include only 2005 and 2006 mortality in our post-construction analysis, with 1998-2003 as the pre-construction period, we found a 98.5% decline in deer mortalities in the treatment and a 2.9% decline in the control (i.e. from a $\bar{x} = 93$ kills pre-construction to a $\bar{x} = 3$ mortalities post-construction). Additionally, we did not document an increase of mortality at the ends of the exclusion fences. We observed lower levels of mortality at the northern end ($t = 2.831$, $P = 0.022$, $df = 7$) and equal levels of mortality in the southern end ($t = 1.274$, $P = 0.238$, $df = 7$); thus, DVC levels were not higher at either end of the fence when compared to non-fenced areas.

Underpass use

We documented considerable differences in underpass use between the underpasses. From a total of 47,759 pictures (UP1: 18,829, UP2: 14,421 and Control UP: 14,509, respectively), we noted similarities between UP2 and the Control UP and a different pattern of use in UP1. UP1 had the highest level of human use, differing significantly from UP2 ($\chi^2 = 7{,}910$, $P < 0.001$) and the Control UP ($\chi^2 = 8{,}010$, $P < 0.001$). It also had the lowest number of mule deer detections both in absolute and proportional terms when compared with UP2 ($\chi^2 = 5{,}238$, $P < 0.001$) and to the Control UP ($\chi^2 = 1{,}782$, $P < 0.001$). In UP2 and the Control UP, we recorded a higher proportion of deer use and frequently detected other wildlife (e.g. coyotes *Canis latrans*, desert cottontail rabbits *Silvilagus audubonii* and birds). Elk were detected only in the Control UP. UP 2 and the Control UP differed in proportion of cattle ($\chi^2 = 1{,}687$, $P < 0.001$) and mule deer ($\chi^2 = 906$, $P < 0.001$). Deer and cattle used the Control UP simultaneously < 10 times. Occasionally, deer and elk were detected using the structure at the same time.

Deer exhibited similar crossing behaviour in all the structures. They would either enter the structure to cross the road directly, or remained in the proximity of the structure, crossing several times in either direction. In the new structures, some photos showed active use of alfalfa, with deer groups frequently spending up to an hour feeding. In the Control UP, movements were direct, but water and salt accumulations often caused deer to remain inside the structure for periods of > 2 hours. Photo evidence showed that deer were often startled by traffic when inside the structures.

We identified two different types of deer movement (Fig. 4A). During certain periods, deer exhibited what appeared to be residential daily movements, crossing in equal numbers east and west. For example, in the Control UP (see Fig. 4A) from December through March, deer displayed a similar number of crossings in each direction. During migration (October-May), however, deer crossed disproportionately more in one direction than the other. When we analyzed UP1 (Fig. 4B) and UP2 (Fig. 4C), we noted that higher numbers of crossings during migratory periods were not as evident in the new structures compared with the control. Nonetheless, both UP1 and UP2 showed spring migratory movements in May 2005 and 2006.

We documented four migratory movements (Fig. 5). We did not detect migratory activity through UP1 and UP2 during the first migration period in autumn 2004 when the mitigation activities were not yet complete. Subsequent migrations, however, did occur through the new crossing structures and were similar in timing to the Control UP. The frequency of crossings during spring migrations was generally higher than during autumn migrations, but autumn migrations extended over a longer time with some migration movements occurring from January to March. Finally, net crossings during migration indicated an increasing use with time of UP1 and UP2 (Fig. 6). Our results show that the number of crossings in the new structures gradually approached the number of crossings in the Control UP. During the first migration period (autumn 2004), UP1 registered 12.6% of the movement observed in the

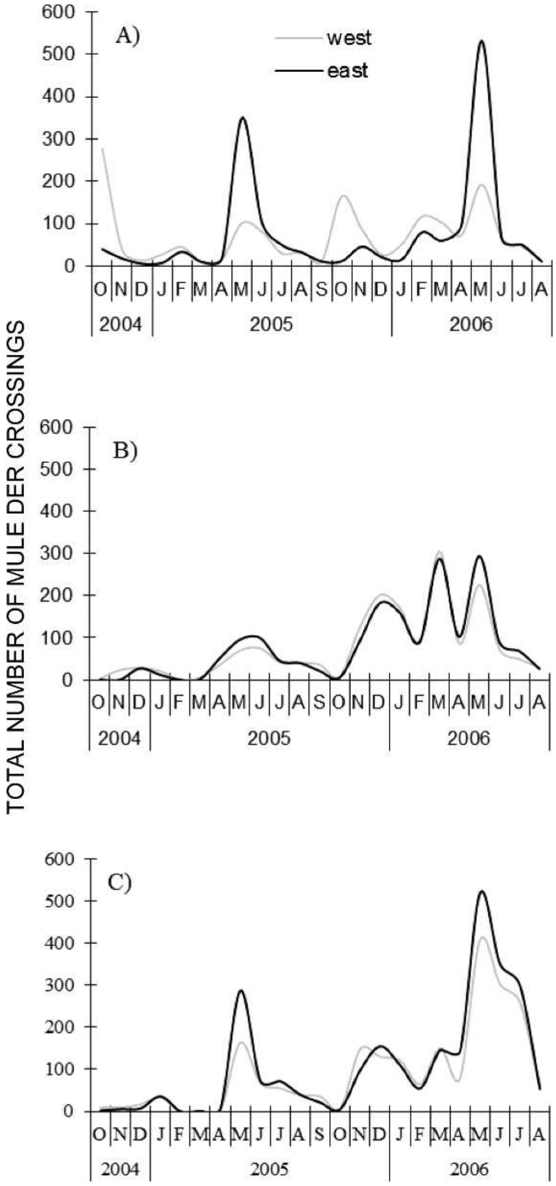

Figure 4. Monthly counts of mule deer crossings detected in both directions (west and east) on the monitored underpasses (A: Control UP, B: UP1, C: UP2) on I-15, southern Utah, USA.

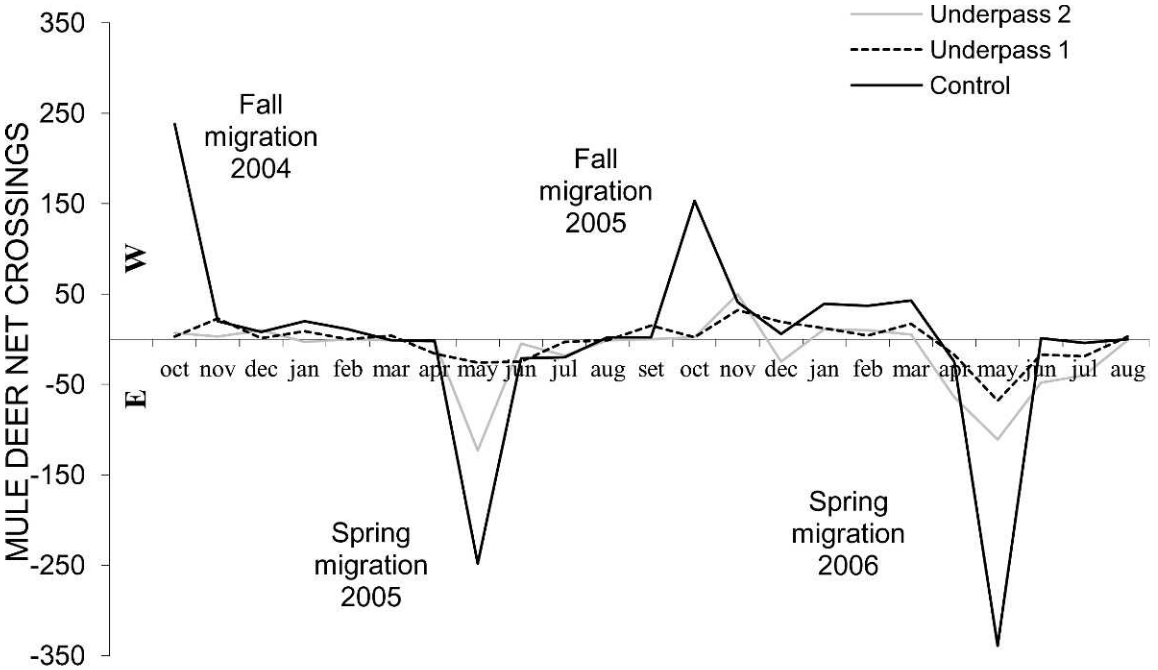

Figure 5. Mule deer net crossings through time (per month) for each underpass on I-15, in southern Utah, USA. Positive values represent movement towards the west; negative values represent movement towards the east.

Control UP, whereas during the last migration sampled (spring 2006) crossings increased to 33%. Similarly, UP2 increased from 5.9% in the first migration to 71.7% in the last migration, nearly matching crossings documented at the Control UP.

Discussion

Based on the three *a priori* established criteria, we considered the I-15 mitigation strategy to be effective in reducing DVC without attendant end-of-the-fence problems. Even when we included the 2004 transition year, when the exclusion fencing was not yet in place until autumn, annual mortality in the study area was reduced by 77%. During most of 2004, the fences had several gaps that were used by deer to gain access to the road. Our mortality reduction of 98.5% is perhaps better than ordinarily expected. This outcome may have been related, in part, to the close spacing of 0.81 km (1/2 mile) of ROW exit ramps that allowed deer easy escape to the wild side of the fence. A qualitative examination of tracks on the escape ramps near the crossings during winter with snow on the ground indicated infrequent use, suggesting that few deer accessed the ROW during the first year post construction. The area in which we worked was also relatively flat, so erosion did not have serious impact on fence integrity. The additional carcass collections conducted in the years 3 and 4 post study (autumn 2006-2008) suggest that the mortality reductions were likely to be long-term (Fig. 7).

The significance of our observed reduction in mortality on the deer population is best understood

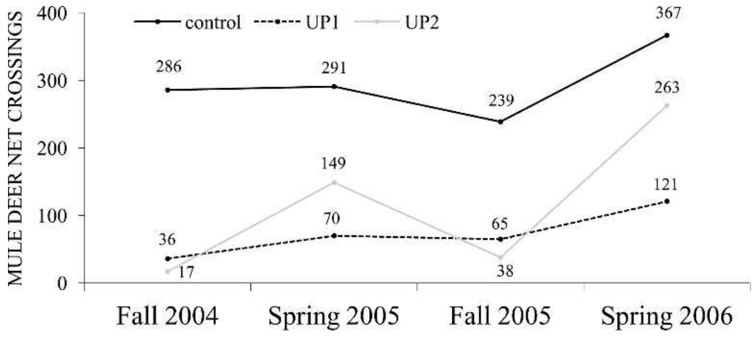

Figure 6. Mule deer net crossings in monitored migration periods (fall: October-January; spring: April-July) during 2004-2006 for each underpass on I-15, southern Utah, USA.

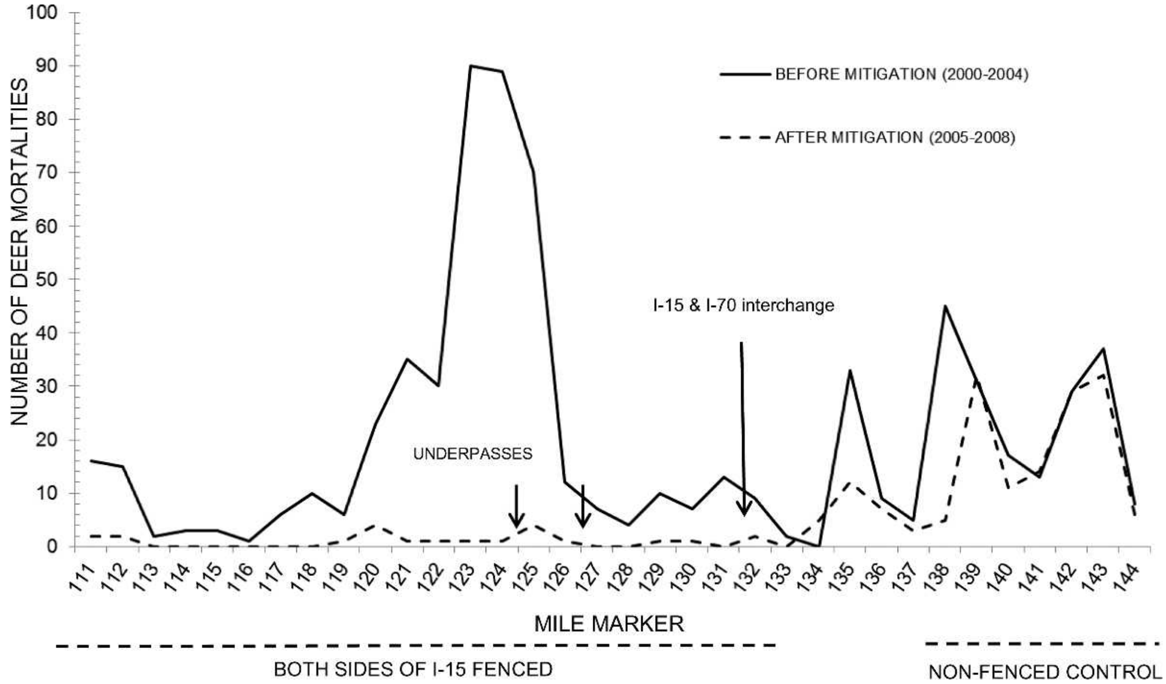

Figure 7. Mortality of mule deer on I-15 near Beaver Utah during pre-construction period (in 2000-2004) and the post-construction period (in 2005-2008). The punctuated line at the bottom of the figure shows the extent of the exclusion fences.

with data on vital rates, however; when survivorship and recruitment data are lacking, it is still possible to estimate how much reduction in mortality is required to reverse population declines. In another study in Utah, Lehnert (1996:62) conducted simulations based on a partial compensation (50%) model and reported that a 60% reduction in road kill was required to halt the population decline displayed by the simulated population using pre-treatment mortality rates. Population information for the I-15 deer herd was insufficient to define a data-based reduction threshold; however, from Lehnert's (1996) research, a 70% reduction was most likely adequate to reverse the declining population trend. Clevenger et al. (2001) reported reductions of 80% in levels of ungulate-vehicle collisions in Banff National Park; Braden (2005) reported a reduction of 83-92% in Key deer *Odocoileus virginianus*-vehicle collisions in Florida and McDonald (1991) described a 70% reduction in moose *Alces alces* mortality in Alaska after mitigation.

An important result is that the mitigation did not cause an end-of-the-fence problem, indicating that deer used the new available underpasses; these deer that may have entered the ROW were able to escape using the ramps. Apparently, exclusion fences extended far enough from deer-kill hotspots (~ 11.3 km (7 miles) north and ~ 19.3 km (12 miles) south of the underpasses) so that few deer moved around the end of the fence. To our knowledge, our study is the only one in which mitigation-exclusion fencing did not cause end-of-the-fence problems. Our results clearly demonstrated that a multi-faceted mitigation combining exclusion fencing, escape ramps and wildlife underpasses was effective in reducing DVCs and should help maintain landscape connectivity for mule deer. We argue that the use of exclusion fencing is justified only in the areas where traffic volumes are high, DVCs are otherwise unavoidable, and where effective structures to promote passage are present.

Management implications

Many factors influence use of crossing structures including location, availability of approach cover, disturbance and the dimensions of the structure itself (Grilo et al. 2010, Clevenger & Waltho 2005). Additionally, human disturbance can interfere with use (Clevenger & Waltho 2000, Rosa 2006); in our study, the very large UP1 showed little use when our cameras recorded human traffic through it. Structures with high openness-ratios are more likely to be used. The most effective structures appear to be relatively short and less tunnel-like. For example, the Nugget Canyon section of Route 30 (M.P. 30-42) in southwestern Wyoming, USA, historically has had high deer mortality, especially during the spring and fall migrations. In 2001, the Wyoming Department of Transportation installed game fencing and a concrete box structure underpass. Its approximate dimensions were 6.1 m wide by 3.1 m high by 18.3 m long (i.e. an openness ratio of ~ 1.02). It received heavy deer use (Gordon & Anderson 2003). Accordingly, six additional underpasses of similar size were built between MP 35 and 40. From 1 October 2009 to 31 May 2010, Sawyer & LeBeau (2010) documented 13,362 mule deer crossings using these underpasses and a bridge span. The relatively short length of the underpasses appeared to facilitate deer passage. A large number of elk (N = 487) also passed through one of the Nugget Canyon underpasses during 2008 and 2009. In our study, the two separate sections of UP2 were short (21.23 m length with an openness-ratio score of 1.62 for each section) and had continual use and the lowest repel rate (failure to cross) of all underpass crossings in Utah (C. Cramer, Utah State University, unpubl. data). No vehicular traffic passed through UP2. It appears that given at least a minimum height and width, the most effective crossings for mule deer are short (20-25 m) and have little human disturbance.

Understanding what is required to reduce DVCs and increase landscape connectivity is not necessarily difficult. To get the appropriate state agencies to act in coordination and cooperation is essential. Effective mitigation requires recognition of the extent of the problem as well as cooperation between agencies in mitigating human-wildlife conflicts. Transportation and wildlife agencies bring different perceptions and perspectives to solutions for solving animal-vehicle collision problems. Transportation agencies are primarily concerned with human safety, whereas the goal of wildlife agencies with regards to roads is reducing DVCs and maintaining the traditional movement patterns (Beckman et al. 2010). Mitigation is less likely to solve the problem if it only accounts for traffic issues and disregards wildlife concerns. Our results should be applicable for other areas if the following are incorporated into mitigation: 1) exclusion fences are maintained and extend well beyond the hotspot(s) of deer mortality, 2) ROW escape ramps are provided to allow animals to escape the right-of-way and 3) the crossing structures are of appropriate configuration to allow animals to cross.

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