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ABSTRACT
After reconstruction of a highway section with three wildlife underpasses, but only limited wildlife exclusion fencing, elk (*Cervus canadensis*)-vehicle collisions (EVC) increased 21%. We retrofitted an existing 1-m right-of-way fence along 4.2 km, raising it to 2.2–2.4 m in height and tying it into underpasses at the project's east end. With no logical western fence terminus, we installed an animal-activated detection system (AADS) and motorist alert signage at a designated at-grade crosswalk to prevent collisions when animals crossed. Our goal was to achieve modified motorist behavior without long-term habituation while allowing wildlife to cross via the crosswalk, promoting highway safety and landscape connectivity. Before-project EVC (9.33/year) declined 97% after the new fencing. Our AADS achieved reduced vehicle speeds (13%) and increased motorist alertness (5.5-fold increase) with signs activated. Average speed reduction and braking response remained significantly higher with sign activation across all 9 years of our evaluation. Thus, our place- and time-specific AADS design successfully modified motorist behavior without habituation.

KEYWORDS
Animal-activated detection system; *Cervus canadensis*; at-grade crosswalk; highway; motorist habituation; wildlife-vehicle collisions

Introduction

Highways are one of the most pervasive forces altering natural ecosystems and impacting biodiversity in the world (Forman & Alexander, 1998; Forman et al., 2003; Trombulak & Frissell, 2000). Wildlife-vehicle collisions (WVCs) are a growing direct threat to wildlife populations (Fahrig & Rytwinski, 2009), and contribute to human injuries, deaths, and property loss (Bissonette & Cramer, 2008; Huijser, Duffield, Clevenger, Ament, & McGowen, 2009a; Huijser et al., 2007). Annually in the United States, WVC cause an average of about 200 human deaths, 30,000 injuries, and economic impacts exceed $8 billion (Huijser et al., 2007). Highways are barriers to movement for many species of wildlife that can fragment populations and habitats, and limit juvenile dispersal (Beier, 1995), genetic interchange (Riley et al., 2006), and ultimately population viability (Sawaya, Clevenger, & Kalinowski, 2013).

A wide range of strategies has been employed to lessen highway impacts to wildlife (Forman et al., 2003; Rytwinski et al., 2016). Wildlife passage structures are typically the most visible yet costly component of mitigation strategies, but have shown benefit for

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many taxa (Bissonette & Cramer, 2008; Clevenger & Barrueto, 2014; Clevenger & Waltho, 2005; Gagnon, Dodd, Ogren, & Schweinsburg, 2011). Wildlife passages with wildlife exclusion fencing have reduced WVC incidence up to 98% (Gagnon et al., 2015; McCollister & van Manen, 2010; Olsson & Widen, 2008), and appropriately sized and properly spaced passages (Bissonette & Adair, 2008) promote highway permeability (Dodd & Gagnon, 2011; Gagnon, Theimer, Dodd, & Schweinsburg, 2007a).

Fences in the absence of passage structures along highways exacerbate the barrier effect (Falk, Graves, & Bellis, 1978; Jaeger & Fahrig, 2004). Conversely, failure to erect adequate fencing in association with passage structures limits effectiveness in reducing WVC and promoting wildlife passage (Huijser et al., 2016; Rytwinski et al., 2016). Fencing can cause animals to cross at fence termini, increasing WVC incidence or 'end-runs' (Clevenger, Chruszcz, & Gunson, 2001; Gulsby et al., 2011; Huijser et al., 2015a; McCollister & van Manen, 2010).

Wildlife passage structures may not be readily feasible due to high cost, unsuitable terrain, land ownership, or other factors. One alternative to costly passages, and even to wildlife-exclusion fencing in some cases, is animal-activated detection systems (AADS; Grace, Smith, & Noss, 2017; Huijser et al., 2006; Huijser, Mosler-Berger, Olsson, & Strein, 2015b). AADS putatively modify driver behavior using flashing signs to warn motorists when animals are adjacent to or within a roadway, and various methods have been used for detecting animals and activating signs (Huijser et al., 2009b). Properly designed AADS reduce the potential for motorist habituation to static or continuously activated signs, which have limited effectiveness (Huijser et al., 2015b). AADS can be integrated with wildlife 'crosswalks' (Lehnert & Bissonette, 1997) where gaps in fencing allow animals to cross in designated areas.

Varying levels of effectiveness in reducing motorist speed and WVC have been achieved with AADS. Huijser et al. (2015b) reported WVC reductions of 33–97%, including Swiss applications that yielded an average 82% decrease. Rytwinski et al.'s (2016) review found that AADS reduced WVC an average of 57%. Ward, Fornwalt, Henry, and Hodorff (1980) AADS reduced traffic speeds by 9.3 km/h. Gordon, McKinstry, and Anderson (2004) documented just a 2.5 km/h reduction with their AADS; when a deer decoy was visible to motorists, speeds decreased up to 20%. Grace et al. (2017) documented a greater response to AADS by tourists who reduced speeds by 3.8 km/h compared to local motorists (1.5 km/h). Huijser et al. (2015b) stressed that AADS should be considered experimental because there is no single reliable system available for universal application.

In 2000, the Arizona Department of Transportation (ADOT) began reconstruction of a 30-km stretch of State Route (SR) 260 in central Arizona from a two-lane to four-lane divided highway, including 11 large wildlife underpasses and six bridges, in five construction phases (Figure 1). The first phase, the 4.8-km Preacher Canyon Section, was completed in 2001 and originally planned to include extensive application of a 2.4-m wildlife-exclusion fence. Prior to construction, a majority of the fence was removed from final plans due to maintenance concerns, leaving just .6 km of short wing fences at the underpasses. Even with three passage structures, elk (*Cervus canadensis*)-vehicle collision (EVC) incidence in the 5 years after reconstruction (M = 11.7 EVC/year) was higher than the 7 years before (M = 9.7 EVC/year; Dodd, Gagnon, Boe, Manzo, & Schweinsburg, 2007a). The next construction phase again included minimal fencing; EVC increased nearly threefold from 2.4/km before

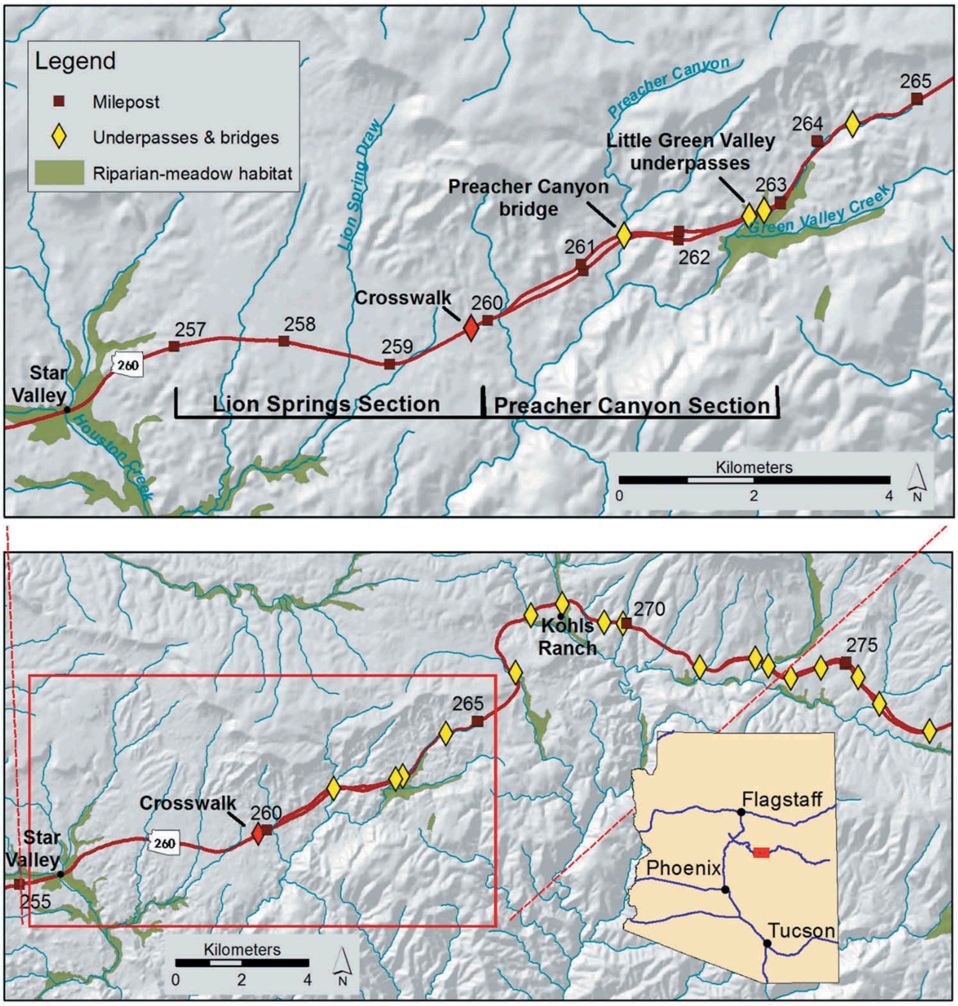

Figure 1. Location of State Route 260, its 30-km reconstructed section with 11 wildlife underpasses and six large bridges, and our study area (red insert box; bottom) enlarged in the top map to show the 4.8-km reconstructed Preacher Canyon Section with three passage structures, the adjacent Lion Springs Section, and location of the designated crosswalk; Arizona.

to 6.5/km after reconstruction. Following the addition of strategically located wildlife fencing prior to the project closeout, EVC declined 81% to 1.2/km (Dodd, Gagnon, Boe, & Schweinsburg, 2007b). These results pointed to the need for additional fencing on the Preacher Canyon Section, but with construction complete, ADOT lacked funding to address increased postconstruction EVC. As such, the Arizona Game and Fish Department and ADOT obtained a Transportation Equity Act for the 21st century enhancement grant in 2004, which provided the means to modify existing fencing on the remaining 4.2 km of the section to limit at-grade elk crossings and funnel animals to existing passage structures, promoting motorist safety (Dodd, Gagnon, & Schweinsburg, 2010; Gagnon, Dodd, Sprague, Ogren, & Schweinsburg, 2010).

Unlike our project's eastern terminus where the fence tied into the wildlife crossings, no means existed to logically terminate fencing on the western end and avoid a potential end run (Clevenger et al., 2001; Huijser et al., 2016). To prevent an end run, ADOT installed an AADS to alert motorists as animals passed around the end of the modified fence, crossing via a defined at-grade crosswalk. We assessed the effectiveness of this AADS and modified right-of-way (ROW) fencing in reducing EVC; unlike passage structures and fencing that rely on modification of wildlife behavior to be effective, our project's success relied on modification of both animal and human behavior. We tested the hypotheses that motorist response (vehicular speed and motorist alertness) to our AADS differed when alert signage was and was not activated, and that this difference persisted across years (9) without motorist habituation.

Methods

Study Area

Our study encompassed a stretch of SR 260 (mileposts 259–262) beginning 10 km east of Payson, in central Arizona, USA (latitude 3415′–34°16′N, longitude 111°08′–111°12′W; Figure 1). It included a 4.2 km reconstructed, but unfenced stretch of the four-lane Preacher Canyon Section, with two bridged wildlife underpasses just beyond its eastern end and a large bridge at the center (Figure 2). It also incorporated 1.6 km of the adjacent two-lane Lion Springs Section to the west with no wildlife enhancements (Figure 1). The terrain was quite rugged and elevations ranged from 1,500 to 1,900 m within 1 km of the highway. The study area was located within the ponderosa pine (*Pinus ponderosa*) association of the montane coniferous forest community (Brown, 1994). Average annual daily traffic volume averaged 7,140 vehicles/day from 2001 to 2010, although peak levels over 18,000 vehicles/day occurred regularly during summer (Gagnon et al., 2010). Traffic volumes the last 5 years of study (2011–2015) increased to an average of approximately 8,900 vehicles/day (ADOT Data Management System, Phoenix, 2016).

Both resident and migratory elk herds occurred within the study area. Resident elk were abundant and especially drawn to a large riparian-meadow complex just east of the study area. The resident herd was augmented in winter by migratory elk coming off the Mogollon Rim escarpment to the north with the first snowfall (Brown, 1994). White-tailed deer (*Odocoileus virginianus couesi*) were common, whereas mule deer (*O. heminous*) were less common.

Project Components

Our project was a hybrid of retrofit fencing intended to intercept elk and other animals approaching the highway and funnel them to the existing bridge and underpasses, similar to Gagnon et al. (2015). It combined an AADS similar to those evaluated by Gordon et al. (2004) and Huijser et al. (2006) at a defined at-grade crosswalk (Lehnert & Bissonette, 1997), utilizing signage to alert motorists to wildlife presence (Grace, Smith, & Noss, 2015; Sullivan, Williams, Messmer, Hellinga, & Kyrychenko, 2004). To minimize complexity of our AADS, we selected a relatively straight stretch on the two-lane Lion Springs Section immediately adjacent to the four-lane divided Preacher Canyon Section (Figure 1).

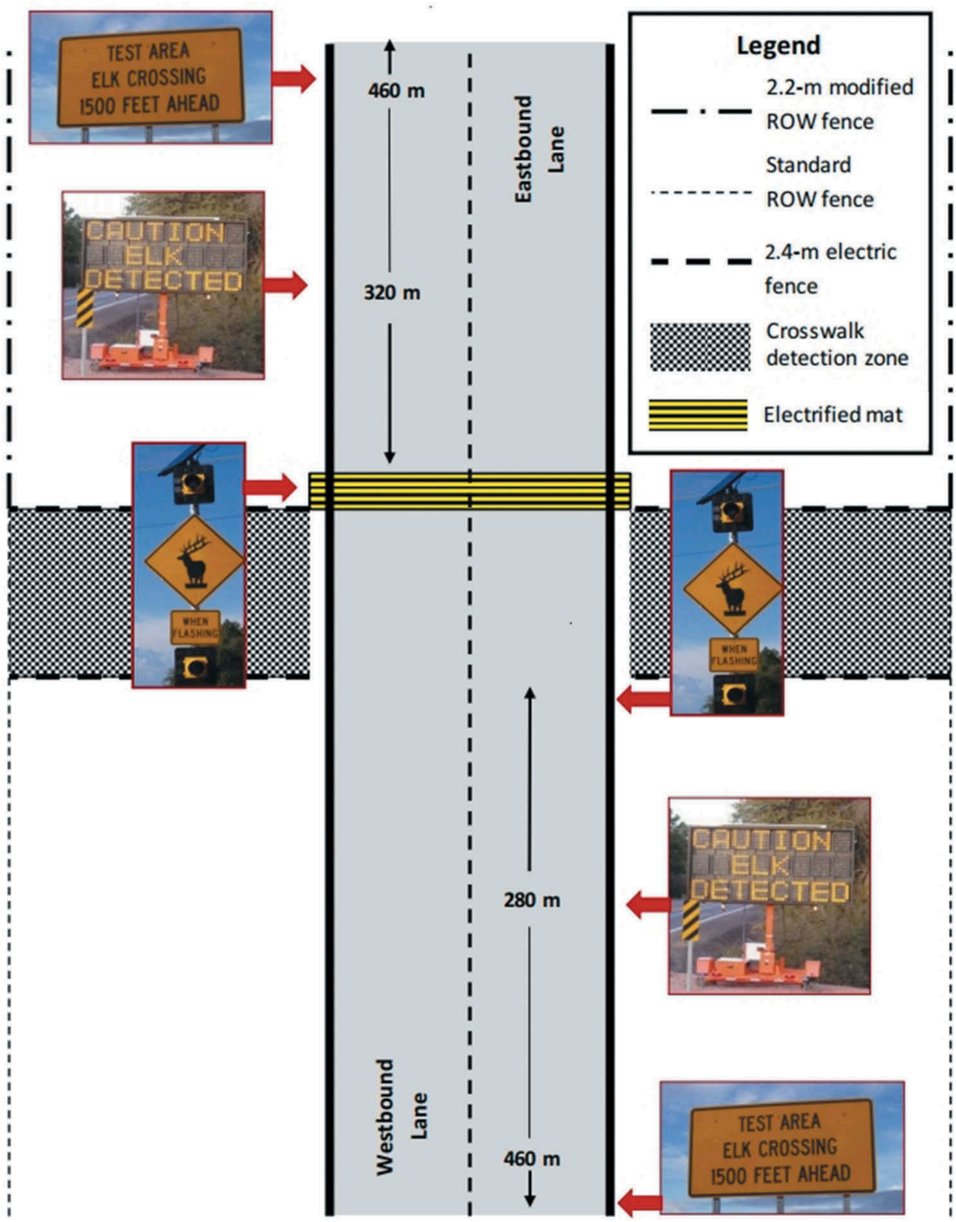

Figure 2. Layout of the array of motorist alert signage installed in 2007 designed to elicit motorist response to the presence of animals on or near the highway at the crosswalk. Signs included static information signs 460 m from the crosswalk in both directions, variable message signs in advance of the crosswalk, and elk warning signs with flashing lights at the crosswalk; the latter two sign types were activated by the animal-activated detection system; State Route 260, Arizona.

We implemented three cost-effective (e.g., <$40/m) designs that raised the existing 1-m high barbed-wire ROW fence to: (a) 2.4 m using 3-m T-posts and barbed-wire, (b) 2.2 m using T-post sleeve extensions and barbed-wire, and (c) 2.2 m with ElectroBraid™ braided rope electric fence (Seamans & VerCauteren, 2006) affixed to fiberglass poles with an electrified wire strand attached to the ROW fence .5 m above ground. These fence designs were intended to be semipermeable to deer, which could pass under the fence, whereas elk could not. The south side of the electrified fence was operated with 120 V AC power and the north side with solar 12 V DC power. In the event that animals breached the fenced corridor and became trapped, escape ramps were constructed to allow exit (Huijser et al., 2015a). New 2.4-m high electrified fencing was erected on both sides of our 20-m wide crosswalk zone, extending approximately 50 m from the ROW fence to the roadway pavement using frangible fiberglass posts (Figure 2).

ElectroBraid Fence, Inc. (Halifax, Nova Scotia, Canada) designed and implemented our AADS-integrated crosswalk (Figure 1). This AADS relied on a tower-mounted infrared camera detection system to detect wildlife in the crosswalk; it employed software sensitive to body heat, movement, and size so that animals smaller than rabbits were ignored. Once detected, radio signals activated signs alerting approaching motorists of the presence of potentially crossing animals (Figure 2). Motorists were presented with a series of signs in each direction: (a) a static sign that read 'Test Area-Elk Crossing 1,500 ft [460 m] Ahead', (b) an AADS-activated variable message sign 280–320 m (depending on lane direction) from the crosswalk that displayed 'Caution—Elk—Detected', and (c) an AADS-activated warning sign with a silhouette of an elk at the crosswalk with flashers (Figure 2).

The westbound variable message sign was first visible to motorists approximately 75 m from the point where the westbound lanes narrowed from two lanes to a single lane at a curve. Conversely, the eastbound traffic traversed a single lane where the variable message sign was first visible to motorists 230 m in advance of the sign.

In 2010, ElectroBraid installed an electrified mat across the highway that extended between crosswalk fences to seal off the gap that allowed animals to breach the fenced corridor (Figure 2). In 2011, CrossTek Wildlife Solutions LLC (Seattle, WA) assumed full operations and maintenance of our AADS and other project elements throughout the remainder of the evaluation.

Our evaluation focused on four performance areas with associated metrics related to the effectiveness of our application of modified fencing integrated with an AADS and motorist alert signage: (a) WVC relationships (highway safety), (b) motorist response and habituation to the AADS, (c) wildlife use of the at-grade crosswalk (wildlife passage), and (d) AADS reliability. Due to limitations in meeting statistical assumptions for analysis of data associated with having a single sampling site, we relied largely on descriptive statistics for most metrics. However, we calculated and compared odds ratios and associated chi-square statistics and confidence intervals (CI) to assess differences in motorist responsiveness when motorist alert signs were and were not activated (Agresti, 1996). Sullivan et al. (2004) similarly employed odds ratios to evaluate signage effectiveness in reducing vehicular speeds and WVC. We considered all results significant at $\alpha = .05$ and reported all means ± standard error (SE).

Wildlife-Vehicle Collision Relationships

With the assistance of highway patrol and ADOT maintenance personnel, we documented WVC from 2001 to 2015, similar to Dodd et al. (2007a) and Dodd, Gagnon, Boe, Ogren, and Schweinsburg (2012). We compiled and summarized nonduplicate WVC records that included the date, time, location (to the nearest .16 km), and species. We compared the mean annual incidence of EVC in the 6 years before (2001–2006) to 9 years after fencing was modified (2007–2015). We assessed the before- and after-fencing incidence of EVC on the adjacent 1.6-km stretch of the Lion Springs Section immediately west of the terminus of the modified fencing and crosswalk for any end-run effect. We assumed that the total costs of each EVC was $17,483 (Huijser et al., 2009a) to estimate the benefit from reduced EVC incidence associated with our project, using the 6-year-before fence-modification mean as a baseline against which to compare to annual EVC reductions thereafter.

Motorist Response and Habituation

To assess motorist response to the AADS and alert signs, we employed Huijser et al.'s (2006, 2015b) model of motorist response where two driver responses can be elicited: (a) lowered vehicle speed and/or (b) increased driver alertness. These responses can lead to motorists avoiding collisions altogether or hitting animals at slower speeds, reducing the risk of injury and property damage.

To evaluate motorist response, we conducted paired 15-min sampling periods at the crosswalk when alert signs were and were not activated. Signs were manually activated with an auxiliary toggle switch for full 15-min sampling periods and we randomly alternated the order of sampling periods with and without signs activated. We conducted paired sampling throughout the year except winter with two-thirds of our sampling done between July and November corresponding to when 71% of SR 260 EVC occurred (Dodd et al., 2012). Sampling was concentrated in the evening (17:00–23:00; 79% of samples) and morning (03:00–09:00; 19%) when 59% and 19% of EVC were documented, respectively (Dodd et al., 2012). We evaluated potential motorist habituation by assessing differences in motorist responsiveness among years using logistic regression with a likelihood ratio test statistic for the overall test and where significant, we compared individual years with odds ratios (Agresti, 1996).

Motorist Speed

ADOT installed a permanent traffic counter at the crosswalk in 2007 that collected data in 15-min intervals, facilitating our comparison of mean vehicular speeds with and without motorist alert signage activated. We used logistic regression and associated odds ratios with 95% CI to evaluate differences in speeds with and without signs activated for Years 2 (2008), 5 (2011), and 9 (2015), and all 3 years combined (Agresti, 1996; Sullivan et al., 2004). Gunther, Biel, and Robison (1998) recommended highway speeds ≤ 73 km/h (45 mph) to reduce WVC. As such, we calculated odds ratios based on the number of 15-min sampling periods where mean vehicle speeds were ≤ 73 km/h versus > 73 km/h; this speed threshold represents an 18% (16 km/h; 10 mph) reduction below the posted legal speed limit (88 km/h/55 mph).

Motorist Alertness

To assess differences in braking response with and without warning signs activated (our surrogate measure of motorist alertness), we determined the proportion of individual vehicles braking (e.g., tapping brakes) during paired sampling periods from each direction as they approached the crosswalk. Due to the differential sight visibility distances to our variable message signs that we hypothesized could influence braking response, we conducted counts with hidden observers for each lane separately at a point beyond where motorists first encountered the signs. We conducted motorist alertness sampling in Years 1 (2007), 2 (2008), 5 (2011), and 9 (2015). We used logistic regression and associated odds ratios and 95% CI to compare individual vehicles braking with alert signage on and off by lane direction. To evaluate motorist braking response over time and assess potential habituation, we used logistic regression and compared the odds of motorists braking among years.

Wildlife Use of the Crosswalk

We documented wildlife use of the crosswalk zone between May 2007 and December 2014 using a video system similar to those employed at SR 260 underpasses by Dodd, Gagnon, Manzo, and Schweinsburg (2007c) and Gagnon et al. (2011). We oriented cameras to record animals crossing the ROW fence, approaching and entering the AADS detection zone, and crossing or repelling away from (or avoiding) the highway, as well as recording passing traffic and monitoring the activation of motorist alert signs. We determined animal passage rates, or the proportion of animal groups that successfully crossed the highway after entering the AADS detection zone from the south side of the highway only due to video equipment and AC power availability. We also determined the proportion of animals in the AADS detection zone that walked around the fence terminus via the gap at the road, thus breaching the fenced corridor.

We simultaneously monitored traffic and crossings by elk and deer that approached within the AADS detection zone to assess relationships to passage rates. We determined traffic levels by counting vehicles passing the crosswalk recorded by the camera aimed at the roadway divided by the amount of time that animals spent in the area until crossing, going around the end of the fence terminus, or leaving.

Animal-Activated Detection System Reliability

We employed video surveillance to determine whether motorist alert signs were properly activated after animals were detected by our AADS. To determine if warning signs were activated as animals entered the detection zone and approached to within 15 m of the roadway, we oriented one camera to allow the viewer to determine if the warning signs were flashing. We calculated the proportion of times that our signs were activated as animals came within 15 m of the roadway compared to when they were not activated (false negatives). Gagnon et al. (2010) previously found false positives (signs activated without animals present) to occur during only 4% of their reliability checks from 2007 to 2010; we did not evaluate this after 2010.

Results

Wildlife-Vehicle Collision Relationships

During the 9 years following fence modification, we recorded only seven WVC within the Preacher Canyon Section including three elk, two white-tailed deers, and single mule deer and black bear (*Ursus americanus*). We traced one EVC in 2011 back to a washout in the fence. The bear and all deer were killed along the stretch of highway with raised barbed-wire fence (and without electrification) considered to be semipermeable to passage by animals other than elk. We recorded a single WVC within the crosswalk over the course of nearly 8 years of video monitoring, a white-tailed deer that was struck in 2009.

In the 6 years before ROW fence was modified, EVC averaged 9.33/year (±1.45). Following fence modification, our mean EVC incidence declined to a mean of .33/year (±.17), a 97% reduction. This decline was maintained even through 2014–2015 when traffic volume increased 51% (M = 11,314 vehicles/day) over the 2007–2013 mean of 7,485 vehicles/day.

In evaluating an end-run effect on the adjacent Lion Springs Section, we found that EVC increased from a mean of .67 EVC/yr (±.19) to 1.11 EVC/yr (±.31) after the Preacher Canyon Section fence was modified. Most collisions occurred along the first .5 km adjacent to the crosswalk where no EVC occurred in the 6 years before fence modification.

Applying EVC cost figures from Huijser et al. (2009a) to our net mean reduction of 8.56 EVC/year after fence modification, offset by the slight (.44/yr) increase on the Lion Springs Section, our annual benefit was $149,655 or approximately $35,600/km/year. Over the 9 years following fence modification, the project accrued benefits exceeding $1.3 million, over twice its cost. This benefit is conservative, as Dodd et al. (2007a) found that annual EVC incidence was associated with average annual daily traffic volume, which increased substantially after project implementation.

Motorist Response and Habituation

Vehicle Speeds

Across all three sampling years, speeds of vehicles traveling in both directions were an average of 11.3 km/h (±.63), or 13%, lower when signs were manually activated for 15-min sampling periods. Across the 3 years sampled, the overall odds of average vehicle speeds being ≤ 73 km/h during a given sampling period were 43:1 when approaching the crosswalk with warning signs activated compared to when they were not activated. Yearly odds of vehicle speeds being ≤73 km/h when signs were activated ranged from 20:1 to 89:1 and were significant across all years (Table 1).

We found a difference among yearly odds ratios (Table 1). The odds of the mean speed being less than 73 km/h with alert signs on versus off in Year 5 were greater than four times the odds when compared to both Years 2 and 9 for which odds did not differ (Table 1). Year 5 average vehicle speeds were the lowest among years and exhibited the highest odds of vehicles traveling ≤73 km/h (89:1) with activated signs.

Braking Response

The mean proportion of vehicles exhibiting a braking response when warning signs were off was .10 ± .01, and increased to .65 ± .01 when signs were activated, a 5.5-fold increase (Table 2). Overall, the odds of braking were significantly greater, 17:1, when approaching the crosswalk with warning signs activated versus when not activated (Table 2).

We found that the proportions of motorists traveling in the westbound lane where signs were encountered closer to the crosswalk showed a higher braking response (.59 ± .01) than vehicles approaching in the eastbound lane (.47 ± .01). The odds of motorists braking when signs were activated in the westbound (19:1; 95% CI;

Table 1. Mean vehicle speeds when crosswalk warning signs were and were not activated in Years 2, 5, 9, and all years combined following fencing modification and erection of motorist alert signage, and the odds (with associated χ^2 and CI) that mean vehicle speeds were ≤ 73 km/h with warning signs activated compared to not being activated, State Route 260, Arizona, USA.

	Years since crosswalk implementation (year)			
Vehicle speed sampling parameter	2 (2008)	5 (2011)	9 (2015)	All[a]
Number 15-min sampling periods	131	68	109	308
Number vehicles counted	11,546	4,732	5,670	21,948
Mean vehicle speed (km/h) ± SE:				
Warning signs not activated	87.8 ± .55	78.7 ± .57	83.1 ± .75	84.1 ± .47
Warning signs activated	73.9 ± .68	67.4 ± 1.04	74.9 ± .96	72.8 ± .55
Difference with signs on (%)	−14.2 ± .91 (16)	−11.3 ± 1.05 (14)	−8.2 ± .89 (10)	−11.3 ± .63 (13)
Odds of $\bar{x}$ speed ≤ 73 km/*h* when warning signs activated vs. off	20:1	89:1	35:1	43:1
χ^2 (all *df* = 1)	28.3 $p < .001$	41.2 $p < .001$	27.4 $p < .001$	98.0 $p < .001$
95% CI	4.0 −88.3	10.5–748.8	4.4–267.5	13.2–141.9

[a]Difference among yearly means: χ^2 = 12.4, *df* = 1, p = .002.
Year 5–3.8:1 (95% CI 1.7–8.7) and 4.1:1 (95% CI 1.6–8.8) greater odds than Years 2 and 9, respectively, of $\bar{x}$ speed being ≤ 73 km/h when warning signs were activated (both p = .002).

Table 2. Comparison of motorist braking response as a measure of alertness when crosswalk warning signs were and were not activated in Years 1, 2, 5, and 9, and all years combined following fencing modification and erection of motorist alert signage, and the odds (with associated χ^2 and CI) of individual vehicles exhibiting a braking response when warning signs were activated compared to not being activated, State Route 260, Arizona, USA.

	Years since crosswalk implementation (year)[a]				
Braking response sampling parameter	1 (2007)	2 (2008)	5 (2011)	9 (2015)	All[a]
Number sampling periods	228	262	436	220	1,146
Number vehicles counted	2,773	5,325	8,419	3,231	19,748
Mean proportion of vehicles braking ± SE:					
Warning signs off	.07 ± .01	.08 ± .01	.10 ± .01	.18 ± .03	.10 ± .01
Warning signs on	.68 ± .02	.69 ± .02	.58 ± .02	.73 ± .03	.65 ± .01
Difference with signs on (% increase)	.61 ± .02 (871)	.61 ± .02 (884)	.47 ± .02 (480)	.55 ± .04 (306)	.55 ± .01 (550)
Odds of braking when signs activated	25:1	20:1	15:1	15:1	17:1
χ^2 (all *df* = 1)	1,151 $p < .001$	2,058 $p < .001$	2,506 $p < .001$	1,192 $p < .001$	6,788 $p < .001$
95% CI	20:1–31:1	17:1–23:1	13:1–17:1	13:1–18:1	15:1–18:1

[a]Difference among yearly means: χ^2 = 227, *df* = 3, $p < .001$.
Year 2—1.4:1 greater odds than Year 5 (95% CI 1.3:1–1.5.1; $p < .001$) of motorists exhibiting a braking response when warning signs were activated compared to not activated.
Year 9—1.6:1 (95% CI 1.4:1–1.8:1), 1.5:1 (95% CI 1.4:1–1.7:1), and 2.2:1 (95% CI 1.9:1–2.4:1) greater odds than Years 1, 2, and 5, respectively, of motorists exhibiting a braking response when warning signs were activated compared to not activated (all $p < .001$).

17:1–21:1; χ^2 = 3,987, *df* = 1, $p < .001$) and eastbound lane (15:1; 95% CI; 13:1–27:1; χ^2 = 2,886, *df* = 1, $p < .001$) were both higher than when signs were off. However, the odds of motorists braking in the westbound lane when signs were activated was higher than the eastbound lane where signs could be seen further away from the crosswalk (1.7:1; 95% CI; 1.6:1–1.8:1; χ^2 = 222, *df* = 1, $p < .001$).

Across the 4 years we sampled, the mean increased proportion of motorists exhibiting a braking response with activated signs ranged from .47 to .61 (Table 2). The odds that motorists exhibited a braking response when signs were activated compared to when signs were not activated ranged from 15:1 to 25:1 and were significant for individual years. The odds of braking with signs activated differed among years ($\chi^2 = 227$, $df = 3$, $p < .001$; Table 2). The odds of a motorist braking in Year 1 did not differ from Year 2, but the odds of motorists braking in Year 2 were slightly higher, 1.4:1, than Year 5. Year 9 exhibited higher odds of braking response when the signs were activated compared to the odds for all other three sampling years, ranging from 1.5:1 to 2.2:1 (Table 2).

Wildlife Use of the Crosswalk

We recorded 13 wildlife species with our cameras comprised of 1,719 individuals within 1,054 groups, of which over half crossed the highway via the at-grade crosswalk. Elk accounted for 55% of the groups and 64% of all individuals (1,067), with a mean passage rate of .34 crossings/approach. The elk passage rate increased steadily over time from < .20 the first 2 years after implementation to above .40 crossings/approach thereafter. We recorded 105 groups of white-tailed deer that exhibited a low passage rate (.08 crossings/approach).

Increasing traffic volume reduced the frequency of successful highway crossings at the crosswalk by elk and white-tailed deer (Figure 3). Nearly three-quarters of elk crossings occurred between 23:00 and 03:00 hours when traffic volume averaged just 36.2 vehicles/h (.6 vehicles/min). When traffic volumes were < 1 vehicle/min, we found that the mean proportion of elk crossing the highway was .40. This dropped to .26 when traffic reached 1–2 vehicles/min, and further declined to .22 as traffic increased to > 2 vehicles/min. Deer showed an even greater avoidance response than elk to crossing the highway with traffic volumes > 1 vehicle/min. All seven groups of deer that crossed the highway did so at traffic levels < 1 vehicle/min (M = .3 vehicles/h).

Between 2007 and mid-2010, we found that 20% of elk (44 groups/84 individuals) approaching the highway crossed around the fence terminus immediately adjacent to the roadway, thus breaching the fenced corridor. Typically, these animals returned to the crosswalk in the same manner without incident. Nonetheless, the potential for elk breaching the fenced corridor and causing collisions with vehicles led us to install an electrified mat across the highway to prevent breaches (Figure 2). After electrified mat installation, elk breaches of the fenced corridor dropped 46%, as only 22 groups (39 individuals) were able to make it past the fence terminus.

Animal-Activated Detection System Reliability

Of the 392 groups of elk that approached to within 15 m of the highway, motorist alert signage was appropriately activated 96% of the time and false negatives occurred just 4% of the time elk were in the crosswalk. In the case of smaller white-tailed deer, 49 groups were detected by the AADS, which triggered motorist alert signage 98% of the time with just 2% false negatives.

Discussion

Our project's ability to use existing structures as wildlife passages to maintain permeability when linked with retrofit fencing (Kintsch & Cramer, 2011) yielded a high return on

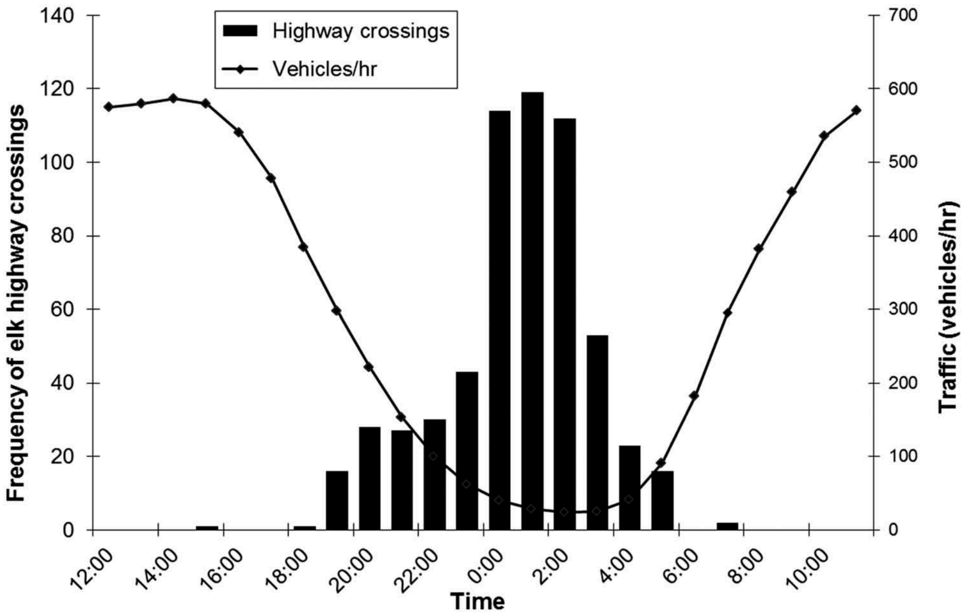

Figure 3. Frequency of elk highway crossings made at the Preacher Canyon Section crosswalk by hour (bars) as determined by video camera surveillance, and average annual daily traffic (AADT) volume (vehicles/h; line) determined by a traffic counter installed at the crosswalk; State Route 260, Arizona.

investment to enhance motorist safety and reduce wildlife mortality. Benefits from reduced WVC exceeded project costs (Huijser et al., 2009a) in < 5 years, similar to Gagnon et al. (2015).

The AADS we evaluated exceeded performance requirements recommended by Huijser et al. (2009b) for successful AADS and warning signage applications: (a) detect at least 91% of approaching large animals (ours detected almost 97%), (b) have a false detection rate of 6–10% (our combined rate for elk and deer was < 4%), and (c) result in a WVC reduction of at least 71% (ours was 97%). As stressed by Huijser et al. (2015b), our system's effectiveness in reducing EVC with minimal motorist habituation after 9 years reflected both its time- and place-specific design and effective fencing integration. Although we detected a minor end-run effect on the Lion Springs Section, the increase in EVC here combined with the after-fencing reduction of EVC on the Preacher Canyon Section still amounted to a nearly 90% overall reduction in EVC.

Increased motorist alertness can reduce vehicle stopping distance by 20.7 m at 88 km/h (Huijser et al., 2009b), as is posted at our crosswalk; average speed with warning signs activated was 72.8 km/h, allowing for even shorter stopping distances. Such reductions are meaningful since the risk of WVC increases exponentially with increasing vehicular speed (Kloden, McLean, Moore, & Ponte, 1997). When reductions in speed are combined with driver alertness, the dramatic and sustained braking response over 9 years points to the potential for AADS and alert signage to achieve sustained modified motorist behavior with limited apparent habituation.

Two other factors contributed to the success of our application: (a) the AADS components were installed at a narrow, two-lane section of highway to reduce complexity and increase reliability; and (b) reduced traffic volumes were experienced during late night-early morning hours coupled with the nocturnal activity patterns of most animals using our crosswalk (Figure 3). Based on the average traffic volume levels during our evaluation and its impact on approaching elk and especially white-tailed deer passage rates, approximately 8,000–8,900 vehicles/day is likely at or near the upper limit for which AADS and crosswalks are appropriate for nocturnal species, assuming nighttime traffic volume is low.

Where traffic remains high through nighttime hours (e.g., Interstate-17; Gagnon et al., 2015) or diurnal target species are involved that are active during peak traffic periods, even well-designed AADS with at-grade crosswalks would likely be ineffective in promoting passage and addressing habitat fragmentation (Jaeger et al., 2005). This will remain an inherent limitation of any system that relies on at-grade (Gagnon, Theimer, Dodd, & Schweinsburg, 2007b) versus below-grade crossings via underpasses where traffic has minimal effect (Dodd & Gagnon, 2011; Gagnon et al., 2007a). However, even relatively low at-grade passage rates for high-traffic avoidance species can contribute to genetic interchange and long-term population persistence (Mills & Allendorf, 1996).

Although effective, our AADS currently has limited commercial availability for easy and widespread application elsewhere. Our AADS was a custom, experimental system and is not suited for widespread off-the-shelf application. However, continued efforts with our vendor to install and validate (with existing cameras) readily available and reliable detection system technologies are ongoing and hold considerable promise. Our ability to achieve effective AADS application with limited motorist habituation warrants pursuit of such cost-effective technology.

In lieu of wildlife crossing structures, retrofitting existing structures that are appropriately spaced and adequate for passage with wildlife-exclusion fence can significantly reduce WVC and maintain habitat connectivity. Where suitable structures do not exist, or at fence ends, and where average traffic volume is < 8,000 vehicles/day, fencing can funnel animals to discrete at-grade crosswalks where AADS and signage can alert motorists to crossing wildlife. Reliable, well-designed, and easily maintainable AADS at such locations can minimize motorist habituation and achieve long-term WVC reduction and improved motorist safety.

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