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Special Issue

Warning Signs Mitigate Deer–Vehicle Collisions in an Urban Area

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ABSTRACT Increasing collisions with deer (*Odocoileus* spp.) and other large animals, and the rise in associated public safety risks and economic costs, have made mitigation strategies a priority for both transportation and wildlife managers. Deer-crossing warning signage is one of the oldest forms of mitigating deer–vehicle collisions (DVCs), but despite their low cost and logistical simplicity, the effectiveness of standard-sized permanent warning signage at reducing DVCs has not previously been adequately determined. We used historical DVC data, based on deer carcass retrieval, to identify and target areas and periods of high collision frequency. We installed warning signs at these high collision frequency locations and then compared DVCs to un-signed control locations. The total number of DVCs at signed hotspots was significantly different in the year after the signs were installed, compared to the 3 prior years ($F_{13} = 4.99$, $P = 0.004$). Although the single year of posttreatment data means the long-term efficacy of warning signage remains unknown, we showed that in the first year after installation, deer-crossing signs targeting high collision locations can be effective at reducing DVCs.

KEY WORDS Alberta, collisions, deer, landscape, mitigation, roads, signs, urban, vehicles.

The rise in deer–vehicle collisions (DVCs) throughout North America have been linked to increasing populations of white-tailed deer (*Odocoileus virginianus*) and humans (Hussein et al. 2007, Morellet et al. 2007). When agricultural or urban development is adjacent to stands of forest, these human-disturbed landscapes create heterogeneous habitats selected by white-tailed deer (Stewart et al. 2000). Urban expansion is, therefore, resulting in more deer–human encounters, of which DVCs are most costly (Tappe and Enderle 2007). Property damage resulting from collisions with ungulates is estimated to amount to almost US$200 million/year in Canada, and >US$1 billion/year in the USA, with 90% of DVCs fatal to the deer, and 65% injurious to humans (Conover et al. 1995, Transport Canada 2003). Reliable and effective methods of mitigating DVCs have become a priority for a diverse group of planners and managers (Farrell and Tappe 2007).

Of Canadian and American transportation agencies surveyed, 77% rarely or never employ wildlife-collision mitigation strategies during transportation planning or construction (Kociolek and Clevenger 2007). When mitigation measures are put into place, they are usually chosen and located arbitrarily, and lack rigorous evaluation of their success at actually reducing DVCs (Putnam 1997). Historical trends in DVC locations can be useful in identifying locations for mitigation, although only 30% of jurisdictions in the USA actually maintain DVC data (Sullivan and Messmer 2003). Temporary mitigation measures also could be improved with analysis of historical DVC data to examine seasonal peaks during which mitigation might be expected to be most useful and effective.

Warning signage is the oldest and most common DVC mitigation measure (Wood and Wolfe 1988). Most of these signs are the size of typical (standard) traffic signs, permanently in place, and warn drivers passively without the use of animations or digital displays. The efficacy of these standard deer-warning signs remains largely unknown, however, with a shortage of experimental data, but a surplus of conflicting opinions (Premo and Premo 1995, Hedlund et al. 2004). Temporary and oversized signs targeting mule deer migratory routes resulted in a 50% reduction in DVCs (Sullivan et al. 2004). Although Rogers (2004) found that temporary and mixed-sized signs did not reduce DVCs, she suggested the mitigating effect of the signs might have been "masked" by high DVC variability in her study area. Pojar et al. (1975) showed that lighted and animated deer-crossing signs reduced driving speeds, but did not examine whether this translated into DVC reduction. Reviews by Knapp (2004), and Mastro et al. (2008), could find no studies into the effectiveness of standard deer-crossing signs at reducing DVCs, only opinions that they do not work.

Our study combined an analysis of historical DVC locations and seasonal peaks in DVC frequency, and an experiment into mitigation at locations that we identified to be DVC hotspots. With this project we aim to furnish planning and managing agencies with evidence on which to decide whether standard warning signs are a suitable mitigation method. We used Geographic Information Systems

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(GIS) to map yearly DVC data within the city limits of Edmonton, Alberta, Canada, and targeted areas of high DVC frequency for experimental warning signage. Post–sign-installation DVC data were compared with un-signed control hotspots to gauge the effect of signs on reducing DVCs. We hypothesized that warning signs will be effective at reducing collisions when placed at high DVC frequency locations.

STUDY AREA

Our study area was the city of Edmonton, Alberta, a city of >1 million people, located in the aspen (*Populus tremuloides*) parkland ecoregion of Canada. The city is bisected diagonally by a major river, the North Saskatchewan. Edmonton's 7,400-ha river valley parks system was one of the largest continuous urban parks in North America and was vegetated with aspen and spruce (*Picea* spp.) forests, shrubs, and open vegetated spaces that included both wild meadows and maintained recreational lands (City of Edmonton 2009). The city was surrounded by wetlands, mixed stands of forest, agricultural fields, and rural residential properties creating a heterogeneous landscape. Dense forests provided both cover and browse, and were found near to open vegetated areas where deer could access nutritionally rich grasses, forbs, and commercial crops. Average snowfall in Edmonton was 130 cm, with an average of 121 days with snow-covered ground (City of Edmonton 2009). Whereas winters were usually long and harsh, summers were warm and mostly sunny. Annual average temperatures were 1.8 °C. Deer were depredated by coyotes (*Canis latrans*) within the city limits, and hunted by humans outside city boundaries.

METHODS

Data for the number and location of DVCs from 2002 to 2007 were derived from records of deer carcasses collected from roads or roadsides within Edmonton city boundaries (S. Exner[Q1], Edmonton Animal Control Services, personal communication). Street address locations of carcasses were converted to a Global Positioning System coordinate for analysis. Location of nearest street address was estimated to within 400 m, and to allow for further variability introduced when carcasses were found some distance from the actual collision location, we defined a DVC location to be within an 800-m-radius buffer. These 800-m-radius DVC buffers were nonoverlapping, and we assumed that each carcass was the result of a DVC. We presumed that carcass data were equally representative of DVCs, based on previous estimates that approximately 90% of all DVCs are fatal to deer (Allen and McCullough 1976, Transport Canada 2003). Sex and species were not recorded for any carcass, and while some mule deer (*O. hemionus*) might be included in the data, most deer carcasses were white-tailed deer (S. Exner, personal communication). We used the geographic coordinates of each DVC to map all locations of DVCs from 2002 to 2007 into a GIS.

The study period for the experiment was June to December 2008. In all years of recorded carcass data for Edmonton, DVCs have peaked in June and November (Fig. 1). Our chosen study period of June to December of 2008 accommodated roadwork logistics, but also targeted a time frame that included both of these seasonal peaks to maximize the potential economic and safety benefits in the event that the signs successfully reduced DVCs.

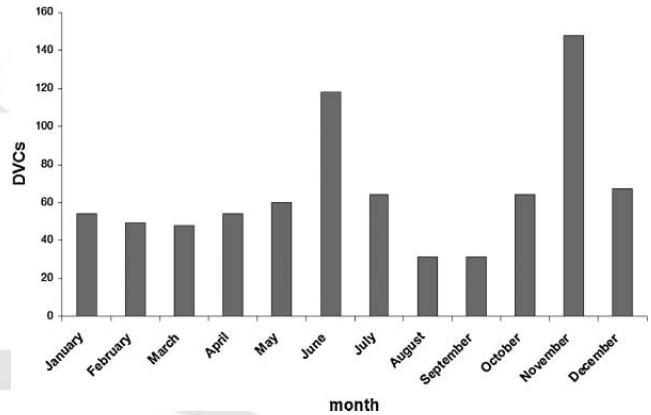

Figure 1. Monthly deer–vehicle collisions (DVCs) within our Edmonton (AB, Canada) study area. Each monthly total represents cumulative collision data for 2002–2007. DVC data are based on deer (*Odocoileus* spp.) carcasses removed by city Animal Control Services within the study area.

We used 2002–2007 carcass data to identify 28 locations of high DVC frequency within the city limits of Edmonton. Each such location was termed a DVC "hotspot," and was defined as an 800-m-radius buffer around locations from which deer carcasses were retrieved in ≥3 of the 6 years of data collection, and multiple carcasses were retrieved from the location in ≥1 of those years. We installed warning signs around 14 of these hotspots, and left the other 14 hotspots un-signed. Treatment and control groups were randomly chosen from among the 28 hotspots. By June 2008, we installed a pair of warning signs at 14 of these hotspots, and left the other 14 hotspots un-signed. Each pair of signs was installed 1,600 m apart, facing opposite directions. This 1,600-m warning-sign range was based on Pojar et al. (1975) who found that drivers reduced their speed for up to 1.6 km past a warning sign, while the effect deteriorated precipitously beyond that. The 1,600-m range also matches the township grid system used in Alberta and elsewhere throughout North America in which road right-of-ways are designated every 1.6 km or 3.2 km. Because carcass locations are defined using this system, this signed range also matches the approximate precision of DVC locations. Where smaller, low traffic-volume sideroads were present within the hotspot, signage was installed on the main road as defined by higher traffic volume. Signs were made from highly reflective yellow Diamond Grade 3 (3M, St. Paul, MN) sheeting, in a standard-sized (90 cm × 90 cm) diamond shape, mounted on 3-m-high posts (Fig. 2). To enhance the specificity of the warning, we mounted a "1.6 km" tag mounted under the main diamond of each sign (Knapp 2004).

Our study was designed as a before–after control impact experiment, comparing the frequency of DVCs at signed versus un-signed locations before and after crossing signs

Figure 2. Deer-crossing warning sign, with distance tab on bottom, placed in Edmonton (AB, Canada) study area. Signs were made from highly reflective yellow Diamond Grade 3 sheeting, in a standard-sized (90 cm × 90 cm) diamond shape, and mounted on 3-m-high posts.

were installed. For our analysis only data from 2005 to 2008 were used because we had access to complete data for each DVC hotspot in those years. At the conclusion of the study period we tabulated the 2008 DVC data, and used 2 analysis of variance tests (ANOVAs; $\alpha = 0.05$) to test whether DVC totals were significantly different in the 2008 year of sign installation compared to DVCs in the previous 3 years at the un-signed hotspots, and at the signed hotspots. In addition, the data for the signed hotspots also were analyzed post hoc with pair-wise t-tests ($\alpha = 0.05$) to individually compare each pretreatment year to the posttreatment year.

RESULTS

Prior to the experimental installation of the signs, and based on retrieved deer carcasses from 2002 to 2007, there were an average of 112.8 DVCs/year in the city of Edmonton, with a high of 139 in 2007. In 2008, the year of our experiment, there was an overall reduction to 78 DVCs citywide. One un-signed hotspot was dropped because it did not meet the hotspot criteria as well as the other hotspots, having had DVCs in only 2 of the 6 years of data, and one signed hotspot was dropped because of outlying DVC data, as determined by the Dixon test (Dixon $Q_{14,95\%} = 0.7186$). We randomly selected 13 hotspots to be signed experimental sites, and 13 hotspots were left un-signed as controls. Before installing the warning signs, during the June to December periods of 2005–2007, there were 66 total DVCs at the 13 hotspots that later had warning signage installed ($\bar{x} = 1.69$ DVCs/location, SD $= 0.64$), and a total of 66 DVCs at the hotspots that were left un-signed ($\bar{x} = 1.69 \pm 0.76$ DVCs/location). During the June to December period of 2008, during which the warning signs were present, there were 5.5 (one carcass was found exactly halfway between a hotspot and a neighboring location, and so each location counted as half a DVC) total DVCs at the signed locations ($\bar{x} = 0.42 \pm 0.64$ DVCs/location), and 13 total DVCs ($\bar{x} = 1.00 \pm 1.41$ DVCs/location) at the un-signed hotspots. Though DVCs were lower across all hotspots during 2008, representing a 7-year low of 78 total DVCs, the number of DVCs at un-signed hotspots in 2008 was not different from the total number of DVCs at hotspots selected for signage in each of 2005, 2006, and 2007 ($F_2 = 0.909$, $P = 0.444$; Fig. 3). In contrast, the number of DVCs at signed hotspots was different in the year after the signs were installed, compared to the 3 prior years ($F_2 = 4.99$, $P = 0.004$). Pair-wise analysis of the mean DVCs at the signed hotspots showed that there were more DVCs in each of 2005, 2006, and 2007 compared to 2008 ($t_{24} = 3.21$, $P = 0.002$; $t_{24} = 3.25$, $P = 0.002$; and $t_{24} = 4.21$, $P < 0.001$).

DISCUSSION

Prior to our study, of the different DVC mitigation methods adequately tested, the combination of wildlife-crossing structures and exclusion fencing had been most successful at reducing DVCs (Tardif 2003, Dodd et al. 2007). These can have limited application, however, with deer-excluding 2.4-m fencing costing up to US$25/m, deer-useable overpasses costing millions of dollars, and deer-useable underpasses being limited by terrain logistics (Vercauteren et al. 2006). Warning signage is the oldest and most common form of DVC mitigation largely because signs are relatively low cost, are nearly maintenance free, and locations for installation usually are not limited by terrain. Despite these advantages, the previous lack of supporting studies left much doubt as to whether deer-crossing signs are effective in reducing DVCs. ~~Premo~~[Q2] Rogers' (2004) lack of success with deer-crossing signs installed during the autumn DVC peak might have been a result of general targeting of entire roadways, rather than more specific hotspot locations that our signage

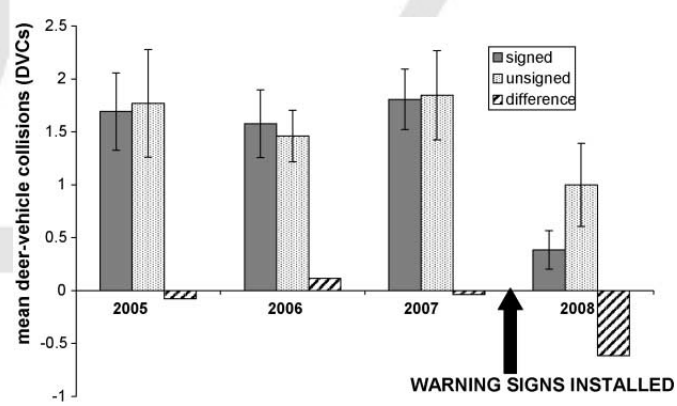

Figure 3. Mean deer–vehicle collisions (DVCs) at 26 experimental locations within the Edmonton (AB, Canada) city limits, before (2005–2007) and after (2008) experimental deer-crossing warning signage was installed. Signs were installed around 13 "hotspot" locations of high DVC frequency, while 13 "hotspots" were left un-signed as controls. DVCs are based on the number of retrieved road-killed white-tailed or mule deer carcasses.

targeted. Our results are the first to show that standard deer-crossing warning signs can be effective at reducing DVCs when placed in targeted, high-risk areas.

While DVCs declined significantly more at the signed hotspots than at the un-signed hotspots, there was a decline in DVCs across the study area during our posttreatment period. Although DVCs declined in 2008, vehicle collisions with other wild mammals increased slightly, from 389 (2007) to 394 (2008), and total vehicle collisions within the city limits also increased, by 1.9% over 2007 collisions (S. Exner, personal communication; City of Edmonton 2008). Using the city of Edmonton's metric of average daily river crossings, overall traffic volumes increased yearly by 1–2% during the study period. A review by Bruinderink and Hazebroek (1996) suggested that there is no clear link between wildlife–vehicle collision frequency and wildlife populations, but the lack of local deer population data prevents us from drawing any conclusions in this regard.

The 34% decline in DVCs that we attributed to our experimental signage can be compared to the 50% decline in DVCs seen with temporary and animated signs (Sullivan et al. 2004), and a 77% reduction in DVCs where fencing, one-way gates, and a system of overpasses and underpasses (Rosa 2006). A review of ungulate–vehicle collisions, by Huijser et al. (2009), concluded that while signage was less effective than fencing, crossing structures, vegetation modification, and animal-detection systems, signage was the most economical. Huijser et al. (2009) estimated that the total cost to society of a single DVC was US$6,617. Total cost of signage and installation for this experiment was US$4,000, and resulted in a reduction of ≥US$49,628 worth of DVCs.

MANAGEMENT IMPLICATIONS

Our results show that historical DVC data can be used to reduce DVCs by allowing managers to identify areas of high DVC frequency for mitigation. Despite a common misconception that standard deer-crossing signs are not an effective mitigation measure, signage targeting DVC hotspots significantly reduced collisions at those locations. Our historical DVC data also revealed 2 pronounced seasonal peaks in DVCs. Although we did not evaluate the effectiveness of seasonal signage, targeting our study period so that it overlapped these 2 seasons captured the period of the year with the greatest DVCs. Temporally targeted mitigation might enhance the effectiveness of warning signage even further, and might help prevent drivers from getting so accustomed to warning signs that the mitigating effect of the signs declines. The continuing rapid increases in DVCs and urbanization across North America only will increase the importance of these mitigation strategies.

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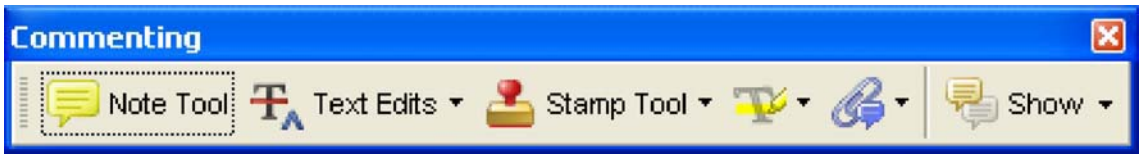

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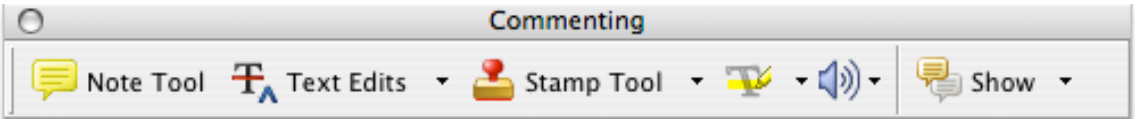

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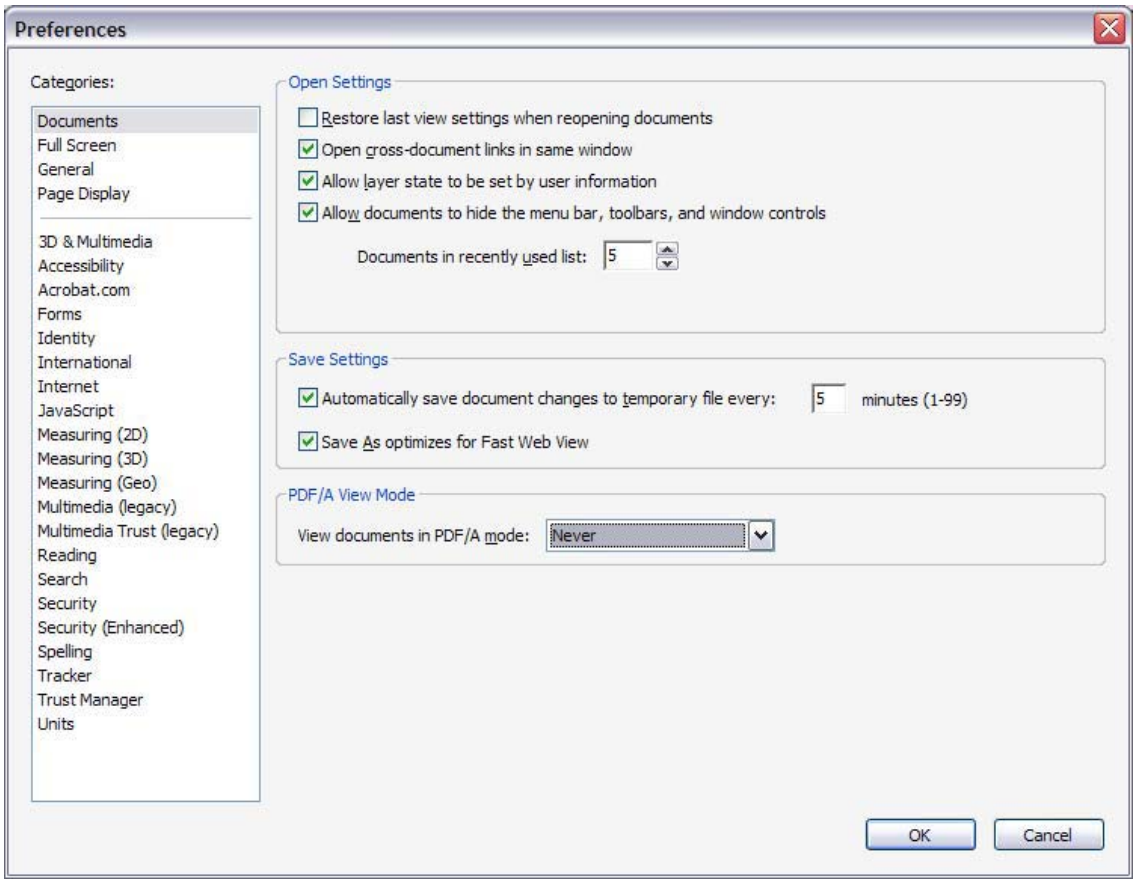

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