Highway mitigation fencing reduces wildlife-vehicle collisions

Anthony P. Clevenger, Bryan Chruszcz, and Kari E. Gunson

Abstract Road mortality can significantly impact some wildlife populations. However, few studies have assessed the effectiveness of measures to reduce wildlife-vehicle collisions (WVCs). We evaluated highway mitigation fencing to reduce WVCs along 3 4-lane sections (phase 1, 2, 3A) of the Trans-Canada highway in Banff National Park, Alberta. We collected data on WVCs and animal intrusions on the fenced right-of-way from 1981 to 1999. We found that WVCs were distributed nonrandomly after fencing and were associated with and close to fence ends. Wildlife-vehicle collisions were greatest within 1 km of fence ends, but proximity to major drainages also likely influenced location of collisions. Post-fencing WVCs were reduced effectively as ungulate-vehicle collisions declined 80%. Wildlife-vehicle collisions and animal intrusions onto the right-of-way were not associated with fence-access points. We recommend methods of modifying motorist behavior and fence design to decrease accident probability at fence ends.

Key words Banff National Park, carnivores, fencing, highway, mitigation, mortality, road-kill, ungulates

Impacts of roads on wildlife species are well documented (Stoner 1925, Haugen 1944, Bashore et al. 1985, Reijnen and Foppen 1994). Although roads have some wildlife benefits, providing habitats for plants and travel corridors, they also can create movement barriers, fragment habitat, and cause significant mortality. Of these impacts, road-related mortality has the most visible and direct effect on wildlife. Road mortality has impacted significantly some species, such as white-tailed deer (*Odocoileus virginianus*), Florida panthers (*Puma concolor coryi*), and black bears (*Ursus americanus*, see Puglisi et al. 1974, Maehr et al. 1991, Brandenburg 1996, Romin and Bissonette 1996*b*). Additionally, WVCs are a serious safety problem for humans in North America, Europe, and Japan (Conover et al. 1995, Groot Bruinderink and Hazebroek 1996, Hughes et al. 1996, Child 1998).

Numerous methods have been used by transportation and natural resource agencies to reduce road-related wildlife mortality (see reviews in Romin and Bissonette 1996*a*, Putman 1997). However, effectiveness of mitigation measures is uncertain. Fencing in conjunction with wildlife overpasses and underpasses may effectively reduce WVCs (Romin and Bissonette 1996*a*). Numerous studies have reported on technical aspects of mitigation fencing (Jones and Longhurst 1958, Halls et al. 1965, Messner et al. 1973, Jensen 1977). However, there is limited information on fencing's effectiveness (Falk et al. 1978, Ward 1982, Ludwig and Bremicker 1983, Feldhammer et al. 1986). Moreover, some research has shown that ungulates were more likely to be hit by vehicles at the ends of mitigation fencing (Reed et al. 1979, Ward 1982, Foster and Humphrey 1995).

Our purpose was to assess efficacy of highway mitigation fencing at reducing WVCs along a major transportation corridor. Our null hypothesis was that WVCs were distributed randomly along fenced sections of the Trans-Canada highway in Banff National Park, Alberta. If our null hypothesis was

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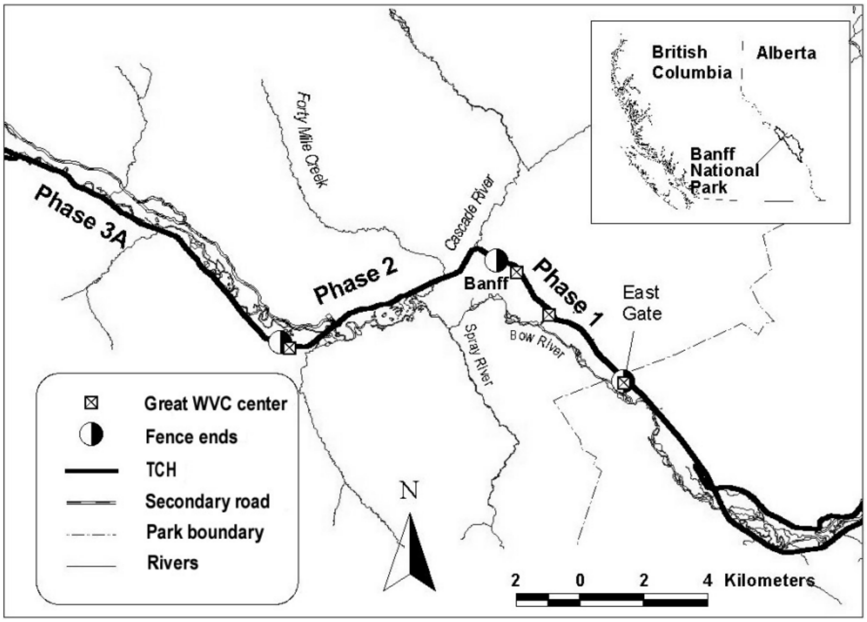


Figure 1. Location of study area and 4 high wildlife–vehicle collision concentration areas on phases 1 and 2 of the Trans-Canada highway, Banff National Park, Alberta, 1984–1999.

rejected, we wanted to know 1) location of high WVC areas and their association with fence ends, 2) whether fencing was effective in reducing WVCs, and 3) whether WVCs and animal intrusions onto rights-of-way were associated with points of potential access (e.g., cattle guards) in mitigation fencing.

Study area

Our study occurred along the Trans-Canada highway (TCH) in Banff National Park (BNP), Alberta, Canada (Figure 1). In BNP, the Trans-Canada highway runs within the Bow Valley, sharing the valley with the Bow River, the township of Banff (population = 9,000), several high-volume 2-lane highways, numerous secondary roads, and the Canadian Pacific Railway. The Bow River Valley in BNP is situated within the Continental Ranges of the Southern Rocky Mountains. Elevations range from 1,300 m to over 1,600 m at the Continental Divide. Valley floor width varies from 2 to 5 km. The climate is continental and characterized by relatively long winters and short summers (Holland and Coen 1983). Vegetation consisted of open forests dominated by Douglas-fir (*Pseudotsuga menziesii*), white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta*), aspen (*Populus tremuloides*), and natural grasslands.

The TCH is the major transportation corridor through the park (park length = 76 km), with an estimated annual average daily traffic volume of 14,940 vehicles/day in 1999, which is increasing 3%/year (Highway Service Center, Parks Canada, unpublished data). Upgrading the TCH from 2 to 4 lanes progressed in phases (Figure 1). The first 46 km of the TCH from the eastern park boundary (hereafter referred to as the east gate) is 4 lanes and bordered on both sides by a 2.4-m-high wildlife exclusion fence (phases 1, 2, and 3A). Phase 1 (10 km), beginning at the east gate, was completed in 1984. Phase 2 (16 km) continued westward from phase 1 and was finished in 1987. Phase 3A (18 km) was a continuation of the 2 previous phases and was completed in late 1997. The remaining 30 km to the western park boundary (Alberta and British Columbia border, phase 3B) was 2 lanes and unfenced. The fenced portion constituted an effective barrier to large-mammal movement. To mitigate the barrier effect, 22 wildlife underpasses and 2 wildlife overpasses were constructed (Clevenger and Waltho 2000). Where fencing intersects roads leading to the TCH, cattle guards were placed in the road to prevent wildlife from entering rights-of-way. There were 7 cattle guards, 2 fence openings for hikers, and 1 railway fence crossing on this 44-km mitigated section of highway.

Methods

Data collection

We collected wildlife–vehicle collision data (the BNP Warden Service) year-round between May 1981 and December 1999. We visited each accident site and recorded WVC date, with information about the species and number of individuals. The WVC site location was plotted as a Universal Transverse Mercator (UTM) coordinate to ±100 m on a 1:50,000-scale topographic map. From January 1997 to October 1999, observations of wildlife entering highway rights-of-way were opportunistically recorded by park personnel as "fence intrusions." We recorded date, time, species observed, number of individuals, and estimated location for each intrusion. UTM coordinates were later assigned to fence intrusions to ±100 m from topographic maps. All potential access points for wildlife onto the highway right-of-way were assigned UTM coordinates. In our analysis of road-related mortality, wildlife included coyote (*Canis latrans*), black bear, wolf (*C. lupus*), bighorn sheep (*Ovis canadensis*), moose (*Alces alces*), deer (*Odocoileus* spp.), and elk (*Cervus elaphus*).

Analysis

We tested whether WVCs were distributed uniformly along phases 1 and 2 of the highway. To do so, we divided the highway into 100-m segments and recorded presence (1) or absence (0) of a WVC in each segment. We generated random numbers (0, 1) for each segment (n=281) to create a random distribution of WVCs. We used a Kolmogorov-Smirnov one-sample test to determine whether the empirical and random distribution of WVCs were similar.

We described the spatial distribution of all WVCs using spatial statistics software (Levine 1999). We performed a cluster analysis using the nearest-neighbor hierarchical clustering algorithm to identify WVC groups that were spatially closer than expected by chance (Sokal and Sneath 1963, Hartigan 1975). In calculating the clusters, we defined 3 parameters: the likelihood or P-value (P>0.05) that threshold distance is obtained by chance, number of standard deviations for the ellipses that are output (n=3), and minimum number of WVCs (n=15) for a cluster. We generated a mean center for each ellipse that contained clustered data points. Using the mean center UTM coordinate, we calculated distance from each ellipse center (hereafter referred to as a high WVC area) to the nearest fence end.

We quantified WVCs at fence ends and fence-end periphery to assess whether the former constituted a significant source of mortality for wildlife. We obtained data for the analysis from the fence end at the east gate, the west end of phase 1 before phase 2 fence construction began, and the west end of phase 2 prior to fence construction for phase 3A. We excluded data from the west end of phase 3A due to small sample size. In each analysis, we compared number of WVCs in 5 2-km road segments, one centered at the fence end and 2 adjacent segments on both sides. We used a chi-square test to determine whether WVCs between the fence end segment and the peripheral 2-km segments on both sides differed significantly.

We investigated effectiveness of fenced sections of highway to reduce WVCs by comparing frequency of WVCs 2 years pre-fencing and 2 years post-fencing. We included all WVCs ≤1 km of the fence end to account for any potential clustering of WVCs associated with the fence. The short time span pre- and post-fencing was used to minimize any potential changes in population abundance during the analysis period. After initial analysis, we subsequently partitioned data into carnivore and ungulate species for further analysis. We used a chi-square analysis to test whether WVCs between the pre-fencing and post-fencing periods differed significantly.

We assumed that fence intrusions were most likely precursors to WVCs. Therefore, to increase our sample size, we combined data from the 2 sources. We calculated distances from WVCs and intrusions (observed data) to the nearest of 10 potential access points on the TCH. To test whether WVCs and intrusions were associated with access points, we used the ArcView GIS Movement extension (Environmental Systems Research Institute 1998, Hooge and Eichenlaub 1998) to generate random points (expected) along the same section of highway. For each phase analyzed, we used the same number of random points as observed data points. We measured distances from the random points to the nearest access point and compared them to the observed distances using a Mann-Whitney U test. The analysis was performed separately on observed data for ungulates, carnivores (including coyotes), and coyotes separately.

Results

Spatial distribution of WVCs

WVC distributions differed significantly from random distributions along phase 1 and 2 of the TCH (Kolmogorov-Smirnov one-sample test, d=0.36, P< 0.01). We therefore rejected our null hypothesis and addressed specific questions regarding effectiveness of mitigation fencing to reduce WVCs.

Four high WVC areas were identified on phases 1 and 2 using the nearest neighbor hierarchical cluster analysis (Figure 1). No high WVC areas were

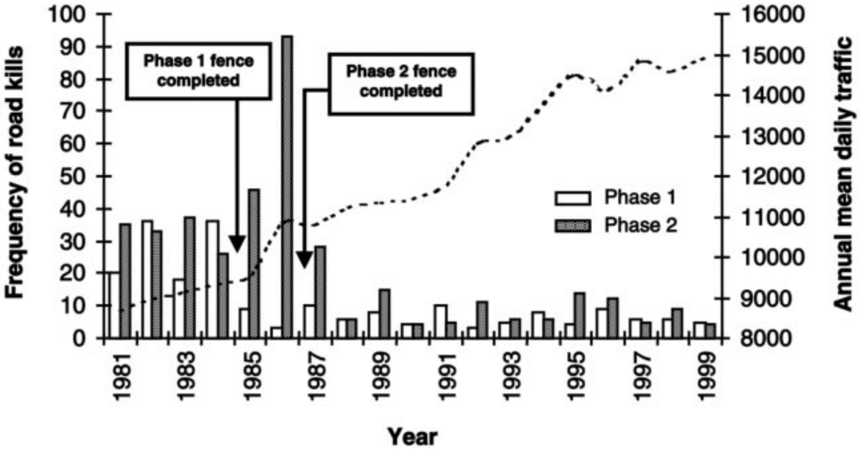


Figure 2. Annual frequency of wildlife–vehicle collisions during a 19-year period along phase 1 (*n* = 206) and 2 (*n* = 395) of the Trans-Canada highway, Banff National Park, Alberta. The year of fence completion is shown for both phases and annual mean daily traffic volume (dotted line).

found on phase 3A because clusters required a minimum of 15 data points and only 10 WVCs on phase 3A were recorded. Three of 4 high WVC areas were associated closely with mitigation fence ends. Of the 3 high WVC areas, the first was located at the east gate. The second was situated at the west end of phase 1 for data collected before phase 2 fence construction began. The third occurred at the west end of phase 2 for data collected before phase 3A fence construction began. Distances varied from the mean center of each ellipse to corresponding fence ends. At the east gate, the west end of phase 1, and the west end of phase 2, the ellipses were centered at distances of 102 m, 686 m, and 1,416 m from fence ends, respectively. On average, these 3 high WVC areas were clustered 735 m from the fence ends. The fourth high WVC area was not associated with a fence end with its center located 4.75 km east of the west end of the phase 1 fence end and 3.46 km east of the second high WVC area center.

We compared number of WVCs within the road segment centered at fence ends to number of WVCs in adjacent segments on both sides of fence ends. At the east gate and at the west end of phase 2 we found WVCs to be highest within fence end road segments compared to the 2 adjacent segments inside and outside the fence (east gate—for all 4 comparisons, $\chi^2_1=13.2$, $P<0.001$; west end of phase 2—only the outermost segments differed significantly from the fence end, $\chi^2_1=4.2$, $P<0.04$). At the west end of phase 1 we found that the first segment to the west of the fence end had significantly more WVCs compared to the fence end segment ($\chi^2_1=14.3$, $P<0.001$). To explain the high kill frequency removed from the fence end, we quantified habitat suitability for elk and deer (Holroyd and Van Tighem 1983) in each of the 5 road segments and tested for significant differences between each using a Mann-Whitney U test. In this post-hoc test, habitat quality did not differ significantly between any of the segments ($P>0.05$).

Fence effects on WVCs

Number of WVCs declined after mitigation fencing was implemented despite annual increases in traffic volumes (Figure 2). This pattern was consistent for all 3 phases. Considering phases separately, WVCs did not occur in equal proportions 2 years before and 2 years after fence construction. For all 3 phases, there were significantly more WVCs in the 2 years pre-fencing compared to the 2 years post-fencing (phase 1, $\chi^2_1=17.8$, $P<0.001$; phase 2, $\chi^2_1=76.2$, $P<0.001$; phase 3A, $\chi^2_1=6.4$, $P<0.012$).

When we combined and analyzed data for all 3 phases by species, we found that ungulate mortality dropped 80%. The mortality reduction was particularly apparent in elk and deer, where declines were significant (elk, $\chi^2_1=71.3$, $P<0.001$; deer, $\chi^2_1=20.3$, $P<0.001$). Among carnivores, overall reduction in mortality only was 16%. Coyote kills occurred in equal proportions pre- and post-fencing ($\chi^2_1=0.15$, $P>0.05$). However, small carnivore sample sizes limit inferences on these taxa.

Wildlife–vehicle collisions and animal intrusions were not more closely associated with access points than expected based on chance alone. The observed distances did not differ from random distances in ungulates ($n=130$, $U=7{,}806$, $P=0.437$), carnivores (including coyotes, $n=122$, $U=7{,}140$, $P=0.483$), or coyotes alone ($n=91$, $U=3{,}835$, $P=0.361$).

Discussion

The WVCs recorded in our study area were not distributed randomly, but occurred in specific areas along the highway. Puglisi et al. (1974) and Hubbard et al. (2000) reported that a small percentage of locations accounted for a large percentage of deer–vehicle collisions in Pennsylvania and Iowa, respectively. Clustering of WVCs previously has been explained by parameters such as animal distribution, abundance, dispersal, and road-related factors including local topography, vegetation, vehicle speed, and fence location or type (Puglisi et al. 1974, Allen and McCullough 1976, Case 1978). Our results showed that along 26 km of the TCH there were few areas of high WVC and all but one of the areas were close to the highway mitigation fence ends.

The high WVC area not associated with a fence end was located 432 m west of an opening where the fence crossed to the outside of the Canadian Pacific Railway tracks. To discourage ungulates from entering the right-of-way, heavy plastic sheets were placed on rail surfaces at the opening to create a slippery surface. The plastic sheeting, however, was unsuccessful in preventing wildlife from accessing the road. The opening accounted for more than 40% of the fence intrusions 6 years after fence installation in 1984 (Waters 1988, Bertch 1991).

The 2-km road segment centered at fence ends had the highest accident rate, and frequency of WVCs tapered off with increasing distance on both sides. Fenced rights-of-way are attractive to herbivores and predators, with greater forage for grazing, greater densities of small mammals, salt, carrion, etc. (Groot Bruinderink and Hazebroek 1996; A. P. Clevenger, unpublished data). Wildlife often access rights-of-way and travel inside fenced areas. Wildlife entering fenced rights-of-way from fence ends can become trapped and likely more prone to be hit by vehicles (Puglisi et al. 1974, Foster and Humphrey 1995).

Highway mitigation fencing and wildlife underpass in Banff National Park, Alberta.

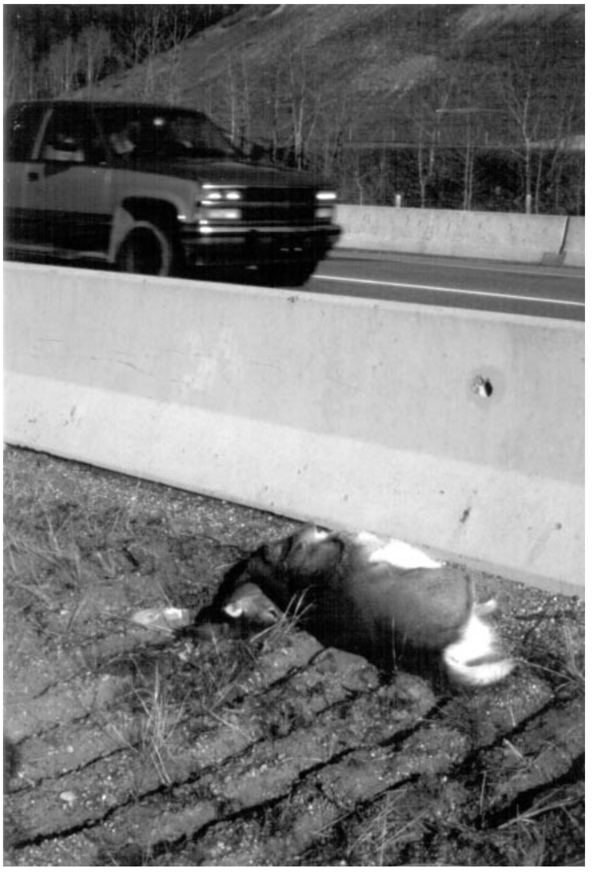
Trans-Canada highway mitigation fencing in Banff National Park, Alberta.

The above pattern was not exhibited by the west end of the phase 1 fence. The highest number of WVCs occurred in the 2 2-km road segments west of the fence end, whereas a lesser number of WVCs occurred at the fence end and adjacent segments inside the fence. Overall, elk and deer comprised 90% of the WVCs in this 10-km area. One possible explanation for most WVCs being away from fence ends may be attributed to TCH alignment relative to the major Bow Valley drainages. A major cervid migration corridor between the Bow Valley and lateral Cascade and Spray valleys passes obliquely across the TCH in front of the fence end (Figure 1). The seasonal deer and elk migratory route between the Bow Valley and these side drainages passed beyond the west end of the phase 1 fence. Ungulates tend to travel parallel to roads before crossing (Puglisi et al. 1974, Bashore et al. 1985, Romin and Bissonette 1996*b*). This resulted in broader distribution and greater number of interactions between elk and the TCH farther west of the fence end rather than at the fence end. Furthermore, research has shown that topography, particularly road alignment with major drainages, strongly influences movement of ungulates toward and across roadways (Bellis and Graves 1971, Carbaugh et al. 1975, Mansfield and Miller 1975, Feldhammer et al. 1986). Other fence ends (east gate and west of phase 2) were not aligned with or close to any major drainage. Therefore, we expected a greater tendency for most cross-highway travel to be "end-runs" at the fence end, as opposed to occurring somewhat away from it.

Despite the fact that most post-fencing WVCs were centered at fence ends, fencing has effectively reduced road-related mortality of wildlife in BNP. Following fencing, there have been 80% fewer accidents involving wildlife, which may be attributed to mitigation fencing and crossing structures. Although population fluctuations can affect WVCs, this was unlikely in our study as deer and elk populations of BNP remained stable or were increasing during pre- and post-fencing periods (Woods et al. 1996). Elsewhere road fencing and crossing-structure installation have decreased vehicle collisions with moose and deer by at least 80% (Ward 1982, Skolving 1985, Lavsund and Sandegren 1991, Child 1998). Conversely, fencing without crossing structures did not reduce deer–vehicle collisions along a Pennsylvania interstate highway, with more kills than expected in unfenced interchange areas (Feldhammer et al. 1986). There were no reductions in WVCs the first year after installing fencing and 7 crossing structures on a Wyoming interstate highway, with accidents concentrated at fence ends. However, by extending the fence an additional 1.8 km to a highway underpass, WVCs, especially involving deer, were reduced significantly (Ward 1982).

Although deer and other ungulates readily cross cattleguards, particularly in heavy snow areas (Ward 1982; A. P. Clevenger, personal observation), our results indicate that WVCs and fence intrusions were not associated with access points. Wildlife–highway interactions were highest around the fence ends, which partially explains the lack of association between WVCs–intrusions and access points.

Few studies have demonstrated that wildlife–vehicle accidents are correlated with traffic volume (McCaffery 1973, Allen and McCullough 1976, Case 1978, Hubbard et al. 2000). Nonetheless, the marked decrease in WVCs along phase 1 and 2 of the TCH after fencing (Figure 2) is convincing evidence that fencing can be an effective measure to reduce WVCs. Although the sample size was small, this pattern held for phase 3A. Fencing's effectiveness in reducing WVCs is illustrated by Royal Canadian Mounted Police accident data for the Banff (fenced) and Canmore (unfenced) sections of the TCH from 1995 to 1997 (Table 1). These 2 sections are adjacent and span 81 km. Wildlife–vehicle collision rates were 4 times greater on unfenced sections compared to fenced. On average, more than half of all accidents on unfenced sections were wildlife-related. The results are compelling, but nonetheless should be interpreted with caution because mortality levels were not compared to population levels. Savings in property damage and wildlife resources are substantial without accounting for human injuries and fatalities.



Road-killed deer on Trans-Canada highway in Banff National Park, Alberta.

Fencing results were mixed for carnivores. The sample size was small for black bear and wolf. However, only 2 of 6 wolf kills occurred on the TCH after fencing. Black bears, grizzly bears (*U. arctos*), and cougars (*Puma concolor*) easily climbed over the mitigation fence, whereas coyotes accessed the right-of-way by going under the fence at numerous ground gaps. The primary concerns in fencing phase 1 and 2 was motorist safety and reducing ungulate–vehicle accidents, therefore the mitigation fence originally was designed to only be ungulate-proof. However, carnivore intrusions onto the right-of-way prompted Parks Canada to bury the phase 3A fence 1.5 m underground.

Future increases in traffic density may only exacerbate existing WVC problems in BNP. Being able to predict WVC locations would be advantageous to Parks Canada and could help focus mitigation efforts. Our study demonstrates that fencing effectively reduces road-related mortality of wildlife in BNP, but clusters WVCs at fence ends. We believe that by modifying the existing fence and rigorously testing the results in an adaptive mitigation approach, we can learn and improve on past efforts. Such road-related measures or combinations of them—such as implementing slow speed zones, installing traffic-calming devices (e.g., speed-bumps), placing cattle guards across the road, and increased lighting—may be effective to reduce WVCs at fence ends. Structural measures include positioning a wildlife passage at the fence end and designing a V-shaped fence end so that animals following the fence are directed back and away from the road. Advanced warning signs triggered by wildlife breaking infrared beams when approaching the roadway have been successful in reducing accidents in Finland and should be tested in BNP and elsewhere (Taskula 1997). For carnivores, outriggers or 1-m extensions on top of and at a right angle away from the fence might deter cougars and black bears from climbing over the fence. Lastly, because motorists are partially responsible for WVCs, improving public education of the problem should be an important part of any future mitigation scheme.

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Literature cited

ALLEN, R. E., AND D. R. MCCULLOUGH. 1976. Deer–car accidents in southern Michigan. Journal of Wildlife Management 40: 317–325.

BASHORE, T. L., W. M. TZILKOWSKI, AND E. D. BELLIS. 1985. Analysis of deer–vehicle collision sites in Pennsylvania. Journal of Wildlife Management 49:769–774.

BELLIS, E. D., AND H. B. GRAVES. 1971. Deer mortality on a Pennsylvania interstate highway. Journal of Wildlife Management 35:232–237.

BERTCH, B. 1991. Monitoring program mitigation measures—Trans-Canada highway twinning. Summary report for Parks Canada, Banff National Park, Alberta, Canada.

BRANDENBURG, D. 1995. Effects of roads on behavior and survival of black bears in coastal North Carolina. Thesis, University of Tennessee, Knoxville, USA.

CARBAUGH, B. J., 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 biologist. Wildlife Society Bulletin 6:8–13.

CHILD, K. N. 1998. Incidental mortality. Pages 275–285 *in* A. W. Franzmann and C. C. Schwartz, editors. Ecology and management of the North American moose. Smithsonian Institution, Washington, D.C., USA.

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.

CONOVER, M. R., W. C. PITT, K. K. KESSLER, T. J. DUBOW, AND W. A. SANBORN. 1995. Review of human injuries, illnesses and economic losses caused by wildlife in the U.S. Wildlife Society Bulletin 23:407–414.

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE. 1998. ArcView GIS. Version 3.1. Redlands, California, USA.

FALK, N. W., H. B. GRAVES, AND E. D. BELLIS. 1978. Highway right-of-way fences as deer deterrents. Journal of Wildlife Management 42:646–650.

FELDHAMMER, G. A., J. E. GATES, D. M. HARMAN, A. J. LORANGER, AND K. R. DIXON. 1986. Effects of interstate highway fencing on white-tailed deer activity. Journal of Wildlife Management 50: 497–503.

FOSTER, M. L., AND S. R. HUMPHREY. 1995. Use of highway underpasses by Florida panthers and other wildlife. Wildlife Society Bulletin 23:95–100.

GROOT BRUINDERINK, G. W. T. A., AND E. HAZEBROEK. 1996. Ungulate traffic collisions in Europe. Conservation Biology 10: 1059–1067.

HALLS, L. K., C. E. BOYD, D. W. LAY, AND P. D. GOODRUM. 1965. Deer fence construction and costs. Journal of Wildlife Management 29:301–304.

HARTIGAN, J. A. 1975. Clustering algorithms. John Wiley and Sons, New York, New York, USA.

HAUGEN, A. O. 1944. Highway mortality of wildlife in southern Michigan. Journal of Mammalogy 25:177–184.

HOLLAND, W. D., AND G. M. COEN. 1983. Ecological land classification of Banff and Jasper national parks. Volume 1: Summary. Alberta Institute of Pedology, Publication M-83-2, Edmonton, Canada.

HOLROYD, G. L., AND K. J. VAN TIGHEM. 1983. Ecological (biophysical) land classification of Banff and Jasper national parks. Volume 3. The wildlife inventory. Canadian Wildlife Service, Edmonton, Alberta, Canada.

HOOGE, P. N., AND W. M. EICHENLAUB. 1998. Animal movement extension to ArcView. Version 1.1. Alaska Biological Science Center, United States Geological Survey, Anchorage, USA.

HUBBARD, M. W., B. J. DANIELSON, AND R. A. SCHMITZ. 2000. Factors influencing the location of deer–vehicle accidents in Iowa. Journal of Wildlife Management 64:707–712.

HUGHES, W. E., A. R. SAREMI, AND J. F. PANIATI. 1996. Vehicle-animal crashes: an increasing safety problem. Institute of Transportation Engineers Journal 66: 24-28.

JENSEN, D. R. 1977. The Fish Creek highway deer passage project. Idaho Transportation Department, Boise, USA.

JONES, M. B., AND W. M. LONGHURST. 1958. Overhanging deer fences. Journal of Wildlife Management 22: 121-124.

LAVSUND, S. AND F. SANDEGREN. 1991. Moose-vehicle relations in Sweden: a review. Alces 27: 118-126.

LEVINE, N. 1999. CrimeStat: A spatial statistics program for the analysis of crime incident locations. Ned Levine and Associates, Annandale, Virginia, and National Institute of Justice, Washington, D.C., USA.

LUDWIG, J., AND T. BREMICKER. 1983. Evaluation of 2.4 m fences and one-way gates for reducing deer-vehicle collisions in Minnesota. Transportation Research Record 913: 19-22.

MAEHR, D. S., E. D. LAND, AND M. E. ROELKE. 1991. Mortality patterns of panthers in southwest Florida. Proceedings of the Annual Conference of Southeast Game and Fish and Wildlife Agencies 45: 201-207.

MANSFIELD, T. M., AND B. D. MILLER. 1975. Highway deer-kill district 02 regional study. Caltrans Internal Report, Sacramento, California, USA.

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

MESSNER, H., D. R. DIETZ, AND E. C. GARRETT. 1973. A modification of the slanting deer fence. Journal of Range Management 26: 233-235.

PUGLISI, M. J., J. S. LINDZEY, AND E. D. BELLIS. 1974. Factors associated with highway mortality of white-tailed deer. Journal of Wildlife Management 38: 799-807.

PUTMAN, R. J. 1997. Deer and road traffic accidents: options for management. Journal of Environmental Management 51: 43-57.

REED, D. F., T. N. WOODARD, AND T. D. I. BECK. 1979. Regional deer-vehicle accident research, Colorado Division of Highways, report No. FHWA-CO-RD-79-11, Denver, USA.

REIJNEN, R., AND R. FOPPEN. 1994. The effects of car traffic on breeding bird populations in woodland. I. Evidence of reduced habitat quality for willow warblers (*Phylloscopus trochilus*) breeding close to a highway. Journal of Applied Ecology 31: 85-94.

ROMIN, L. A., AND J. A. BISSONETTE. 1996*a*. Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. Wildlife Society Bulletin 24: 276-283.

ROMIN, L. A., AND J. A. BISSONETTE. 1996*b*. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle reservoir, Utah. Great Basin Naturalist 56: 1-11.

ROYAL CANADIAN MOUNTED POLICE (RCMP). 1995-1997. Year end collision analysis, 1995-97. Royal Canadian Mounted Police, Banff, Alberta, Canada.

SKOLVING, H. 1985. Traffic accidents with moose and roe-deer in Sweden. Report of Research, development, and measures. Pages 317-326 *in* Routes et faune sauvage. Service d'Etudes Techniques de Routes et Autoroutes, Bagneaux, France.

SOKAL, R. R., AND P. H. A. SNEATH. 1963. Principles of numerical taxonomy. W.H. Freeman, San Francisco, California, USA.

STONER, D. 1925. The toll of the automobile. Science 61: 56-57.

TASKULA, T. 1997. The moose ahead. Traffic Technology International 42: 170-173.

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

WATERS, D. 1988. Monitoring program mitigative measures—Trans-Canada highway twinning. Final report to Parks Canada, Banff National Park, Alberta, Canada.

WOODS, J. G., L. CORNWELL, T. HURD, R. KUNELIUS, P. PAQUET AND J. WIERZCHOWSKI. 1996. Elk and other ungulates. Pages 1-29 *in* J. Green,, C. Pacas, L. Cornwell, and S. Bayley, editors. Ecological outlooks project. A cumulative effects assessment and futures outlook of the Banff Bow Valley. Prepared for the Banff Bow Valley Study. Department of Canadian Heritage, Ottawa, Ontario, Canada.

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