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Animal-Vehicle Collision Reduction

EVALUATION OF MEASURES TO MINIMIZE WILDLIFE-VEHICLE COLLISIONS AND MAINTAIN WILDLIFE PERMEABILITY ACROSS HIGHWAYS IN ARIZONA, USA

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Problem Statement

Major construction upgrades are underway along a 28km section of State Route 260 in central Arizona that exhibits a high incidence of collisions (e.g., >4km/year) between wildlife, primarily Rocky Mountain elk (*Cervus elaphus*), and vehicles. As this highway is being upgraded from a narrow two-lane roadway to a four-lane divided highway, 12 sets of large underpasses (in addition to 5 sets of bridges) are being constructed to facilitate wildlife passage across the highway corridor and minimize the incidence of wildlife-vehicle collisions. Construction is being accomplished in stages (5 total), with the first 8-km section with two underpasses completed in 2001 and the second 12-km section with five underpasses nearing completion. Limited elk-proof fencing has been erected in association with the completed underpasses and those under construction, and alternatives to fencing (e.g., large boulder rip-rap and steep cut slopes) are also being applied. Our research focuses on evaluating the effectiveness of the underpasses, fencing, and other measures in reducing the incidence of wildlife-vehicle collisions and maintaining wildlife permeability. Our findings are being applied though adaptive management to make modifications to underpass design and fencing to increase use by wildlife.

Project Objectives

The primary objectives of our research project, ongoing since 2002, are to:

1) Determine the effectiveness of the full complement of measures to minimize the incidence of wildlife-vehicle collisions along State Route 260.
2) Evaluate the degree to which wildlife permeability across the highway is maintained.
3) Provide ongoing construction implementation guidance to Arizona Department of Transportation (ADOT) project managers throughout all construction phases.

Funding Source and Total Budget

Funding through 2004 for our current research project is provided by a grant from ADOT's Transportation Research Center ($217,000), our Federal Aid in Wildlife Restoration Act Project W-78-R ($120,000), and from the USDA Forest Service, Tonto National Forest ($31,500). An agreement with ADOT for funding through 2006 ($259,000) is near finalization. The Federal Highway Administration has also contributed $40,000 toward this research project.

Methodology

To assess the overall effectiveness of measures to reduce wildlife-vehicle collisions, we employed a standardized, multi-agency wildlife-vehicle collision tracking form. This tracking, ongoing since 2000, allows us to assess changes in collision rates pre- and post-highway upgrade, as well as against control areas.

To assess the effectiveness of underpasses as well as elk-proof fencing, escape jumps and one-way gates on the completed highway section, both video camera monitoring and prepared track bed counts are being used. Cameras and track beds have been placed inside the two underpasses, at the mouth of the underpasses, and approximately 60m away to determine relative rates of passage by approaching wildlife. At each underpass, we installed four-camera infrared video monitoring systems with multiple triggers. Camera systems have also been deployed at the terminus of the fencing to assess wildlife passage around the end of the fence. In addition to counting and identifying individual animals recorded on videotape, we also characterize behavioral response by wildlife when approaching and using the underpasses.

To assess wildlife crossing patterns in relation to the highway and its upgrade, 30 elk have been instrumented with global positioning satellite (GPS) receiver collars, including five with ARGOS satellite data transmission capabilities. Information from these collars, though preliminary in nature, has been used to assess the extent to which fencing should be constructed in association with underpasses. Geographic information system (GIS) analysis has been employed to identify elk highway crossings and concentration areas immediately adjacent to the highway.

Summary of Findings

A total of 181 collision reports have been logged to date. For the section where construction is complete, no change in the number of collisions has occurred post- versus pre-construction. This may reflect the limited amount of fencing associated with the two underpasses, allowing animals to cross the highway along most of the section.

GIS analysis of GPS locations for nine collared elk identified 675 highway crossings between May 2002 and July 2003; data from all collared elk yield >2,500 identified crossings. Only six percent of the crossings occurred at the two underpasses on the completed section; additional fence may be needed to increase underpass use and reduce the collision rate. These data have shown highway engineers the relative efficacy of different fencing options in terms of the probability of intercepting elk crossing the highway. On the next section of highway to be constructed, GPS data show that 72 percent of elk crossings could be intercepted by fencing only 25 percent of the section.

To date, 1,730 animals have been recorded by video monitoring of the two underpasses, including 1,435 elk and 257 white-tailed deer (*Odocoileus virginianus*). Elk passage rates (74% versus 51%) and numbers of animals through the underpasses (700 versus 184), as well as behavioral response (e.g., 11% versus 28% alarmed flight from underpasses) were significantly different, and appear to be tied to underpass design. To date, only one deer has successfully crossed the underpasses, and instead, they typically pass around the fence terminus (n=170). Insights from this monitoring have been used to modify future underpass design at other sections along State Route 260. A significant relationship between underpass crossings and traffic volume suggests that elk do not cross through either underpasses when traffic volume is greater than seven vehicles/minute. Since completion in late-2001, overall use of the two completed underpasses has increased steadily, and now approaches 90 percent for both underpasses combined. However, a drop in passage rate occurred during spring 2003, possibly reflecting “uneducated” migrating, non-resident elk encountering the underpasses as they moved to summer range; it is anticipated that a similar decline will occur in the fall as migrating elk move toward winter range.

Implications for Future Research

As additional sections of State Route 260 are completed, increasing the number of underpasses that we will evaluate, our ability to correlate wildlife use to underpass design will also increase. Obtaining GPS data from all 30 collared elk (May 2004) will allow us to more definitively identify where fencing should be constructed to optimize its potential to funnel animals toward underpasses and reduce the incidence of collisions, while at the same time maintaining wildlife permeability across the highway. A TEA-21 enhancement grant has been submitted to retrofit the Preacher Canyon with additional fencing (1.5km) to funnel a greater proportion of elk toward underpasses and bridges; post-fencing monitoring will be conducted for two years to assess the change in elk crossing behavior. Electronic animal detection/motorist alert systems will also be placed at the ends of fencing to attempt to modify motorist behavior. Ultimately, our adaptive management efforts with ADOT will result in increased highway safety and use of crossing structures by wildlife.

For more information on this project: www.gf.state.az.us.wildlife_conservation/research

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LARGE ANIMAL-VEHICLE COLLISIONS IN THE CENTRAL CANADIAN ROCKY MOUNTAINS: PATTERNS AND CHARACTERISTICS

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Abstract: The trends of increasing traffic volumes and road densities will only magnify the already adverse effects roads have on large mammals and other vertebrates. Development of practical highway mitigation will rely on an understanding of patterns and processes that result from highway accidents, which involve elk *Cervus elaphus* and other large animals. We specifically address three areas relating to the patterns and characteristics of large-animal vehicle collisions on different road-types in the Central Canadian Rocky Mountains. First, we investigate the spatial error associated with reported wildlife-vehicle collisions (WVCs). Second, we look at the demographic and temporal patterns of elk and wildlife-vehicle collisions on different road-types. Finally, we investigate the type of vehicles involved in WVCs and what conditions contribute to injury-related accidents. We found that the average reporting error from park wardens, highway maintenance contractors and from Royal Canadian Mounted Police (RCMP) data ranged from 300m-2000m. The sex ratio of elk-vehicle collisions (EVCs) was significantly different from that found in the population, and highly skewed towards greater male mortality during the 15-year period. The age ratio of EVCs was highly skewed towards greater subadult mortality. We found no difference in marrow fat content between highway and railway killed elk, but both had higher fat content than predator-killed elk. EVCs were significantly higher on the Trans-Canada Highway (TCH) in the province which had the highest traffic volumes. The TCH in Banff National Park (BNP) had a significantly higher rate of EVCs than the secondary highway (93S) in Kootenay National Park. EVCs declined over time on the unmitigated section of TCH in BNP and on highway 93S, even though traffic volumes were increasing. We found that local elk abundance was decreasing and was the driving force in EVC rates; however, traffic volume determined the rate of EVCs on different road types. WVCs occur more often than expected at dusk and night periods and on weekends. Injury-related WVCs are more likely to occur in dry conditions than in slush, snow or icy conditions. Injury-related WVCs are more likely to occur with smaller vehicles than in larger vehicles. Further, larger vehicles were involved in more WVCs than expected on two of our road-types. In conclusion, spatial road-kill data can aid in determining location of mitigation measures, e.g., wildlife signage and crossing structures. Patterns of WVCs can be valuable in devising mitigation based on specific hour of day or season when collision frequencies are highest, and what individuals within a population are most susceptible to road-kills. Factors contributing to WVCs, such as traffic volumes and elk abundance, can help managers predict long-term viability of wildlife populations with incurring road mortality.

Introduction

Within the last 30 years, roads with vehicles probably overtook hunting as the leading direct human cause of vertebrate mortality on land (Forman and Alexander 1998). Current estimates reveal that tens of millions of vertebrates are killed on roadways each year. Surveys of state transportation and natural resource agencies indicate that in the United States alone, approximately 0.5 to 1.5 million deer are killed on roadways annually (Cook and Dagget 1995, Romin and Bissonette 1996a, Conover 1997).

For years, collisions with wildlife have been a problem in the Central Canadian Rocky Mountain national parks and a cause for concern among park managers and transportation planners. The long-term trend and prospects are for increasing traffic volumes on the Trans-Canada Highway (TCH) and other primary roads in the parks. Development of practical highway mitigation will rely on an understanding of patterns and processes that result from highway accidents, which involve large animals.

The national and provincial parks collected information since the 1960s on wildlife-vehicle collisions in the Central Canadian Rocky Mountains (Flygare 1978, Damas and Smith 1982, Fraser and Pall 1982, Sanderson 1983). Inevitably, there will be a certain degree of error in describing the event and location, due to many people reporting road-killed wildlife and motor vehicle accidents. We are not aware of any information from the scientific literature or technical reports that attempt to measure the spatial error associated with each wildlife-vehicle collision (WVC) report. In our first analysis we devised a way to arrive at a road-kill reporting error estimate. This measure will be essential for analyses of site-specific features of WVCs, and under certain circumstances enable a larger amount of less-spatially accurate road-kill information to be utilized for study.

The construction and operation of roads across ungulate ranges is a concern to many wildlife managers (Romin and Bissonette 1996a, Cole *et al*. 1997, Putman 1997); however, most studies have focused on deer-vehicle collisions and the means of reducing them (Puglisi *et al*. 1974, Bashore *et al*. 1985, Feldhammer *et al.* 1986, Hubbard *et al*. 2000). Little attention has been given thus far to the characteristics of elk-vehicle collisions (EVCs) (Singer 1975, Ward *et al.* 1980, Boulanger 1999), despite elk *Cervus elaphus* being the dominant ungulate species in many western ecosystems.

We focused our second analysis on elk-vehicle collisions where we addressed demographic, seasonal mortality, and highway-related temporal and spatial patterns of accidents that might reveal ways in which EVCs may be reduced by mitigation. In our third analysis, we used wildlife-vehicle-collision data collected by the Royal Canadian Mounted Police (RCMP) to determine the effects of time of day, day of week, and type of vehicle on collisions. In addition, we looked at what road-related factors, such as road conditions, cause injury-related motor vehicle collisions in the Central Canadian Rocky Mountains.

Study Area

Our research was carried out in the Central Canadian Rocky Mountains approximately 150km west of Calgary, in southwestern Alberta and southeastern British Columbia (fig. 1). The area comprises mountain landscapes in Banff, Kootenay and Yoho national parks and adjacent Alberta provincial lands.

The TCH in Banff National Park (BNP) runs along the floor of the Bow Valley, sharing the valley bottom with the Bow River, the township of Banff (population 9,000); several high-volume-two-lane highways, numerous secondary roads; and the Canadian Pacific Railway. The highway is a major commercial motorway between Calgary and Vancouver. In 1998, annual average daily traffic (AADT) volume at the BNP East entrance was 14 600 vehicles per day, and summer annual traffic volume was 21,500 vehicles per day (Parks Canada Highway Service Centre, unpublished data). Other roads in the study area we investigated consisted of two-lane primary roads that served as arterial transportation routes. AADT volume on the primary roads Highway 93S and 40, were respectively 2,870 and 2,150 vehicles per day in 1998 (Parks Canada Highway Service Centre and Alberta Infrastructure, unpublished data). All highways in this study were two to four lanes and unmitigated (no fence or wildlife crossing structures).

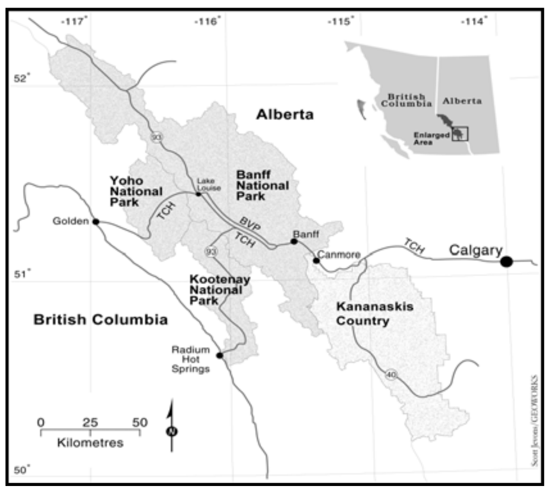

Fig. 1. Location of study area and highways used to examine patterns and characteristics of large mammal vehicle collisions in the Central Canadian Rocky Mountains.

Methods

Error Reporting

National parks and Alberta province

Since January 1999 we made an effort to maximize WVC reporting and its accuracy. In doing so, we contacted everyone responsible for collecting and reporting wildlife road-kills in Banff-Kootenay-Yoho national parks and the province of Alberta (Bow Valley and Kananaskis Country). Cooperators included national park wardens, provincial park rangers and the private highway maintenance contractor (Volker-Stevin).

We provided all cooperators with coloured pin-flags to be carried with them in their vehicles. After collecting road-killed wildlife they were advised to mark the site of the WVC by placing the pin-flag in the right-of-way and report back to us via telephone, fax or email. Most accidents and pin flagging were reported to us within 48 hours.

The reported location of WVCs was recorded by the collaborators by describing the location with reference to a nearby landmark (e.g., 0.3km east of park east gate). The true location of a WVC was acquired by visiting the reported accident site; recovering the pin-flag, and obtaining the actual location by measuring the odometer distance from the same reported nearby landmark to the pinflag. UTM location coordinates were also collected using a differentially correctable global positioning system (GPS) unit (accuracy = $\leq$ 5 m). We calculated the reporting distance error for each WVC by subtracting the actual distance to the landmark from the reported distance to the same landmark. We calculated the average ($\pm$ SD) reporting error for each collaborator and within the national parks for each method of reporting.

Royal Canadian Mounted Police

As a separate error analysis from the national parks and province, we obtained WVC data from the transportation section of Alberta Infrastructure, from 1991 to 2000 for BNP highways, and Alberta provincial highways. The WVCs were derived from vehicle accident forms completed by the Royal Canadian Mounted Police (RCMP) at the collision site. A WVC location is noted on the report form by giving a distance measurement in kilometres (or metres) to the closest street, highway, town, etc. This measurement is then converted into standard kilometre postings (to the nearest metre) by the transportation section of Alberta Infrastructure. Alberta Infrastructure provided us with the geographic location of each kilometre posting on highways in the study area.

We selected kilometre-posted accident locations from the RCMP records that corresponded to WVCs, from which we had acquired differentially corrected GPS locations from our pin-flagging and error reporting exercise (see above). We plotted both RCMP-reported WVC locations, and our accurate WVC locations (<3 m error) on a differentially corrected highway layer in a GIS. We measured the spatial error between each paired RCMP reported location and true WVC location. Distance measurements were calculated from the two corresponding WVC locations using Edit Tools Version 2.4 in ArcView GIS (ESRI 1999). An average distance error and standard deviation were calculated for the RCMP WVC data set.

Elk-Vehicle collisions

Data collection

Parks Canada (Banff, Yoho, Kootenay national parks) and Alberta Natural Resources Service recorded EVCs year-round. The site of each accident was visited and the date of the kill reported, along with information regarding the number of individuals, their sex and age. We analyzed data from all reported EVCs occurring on unmitigated sections of highway.

We obtained annual traffic volume data on national park roads from Parks Canada (Parks Canada Highway Service Centre, unpublished data) and on provincial roads from the province of Alberta (Alberta Infrastructure, unpublished data). Elk relative abundance data were obtained from Parks Canada and Alberta Natural Resources and used for the analysis of the relationship between relative abundance (as a measure of annual population trends) and rates of EVC. We used elk relative abundance estimates from annual classified ground counts in the national parks (KNP and BNP), conducted in spring and autumn between 1985 and 2001 (Woods 1990, Woods *et al*. 1996, Parks Canada, unpublished data).

Sex and age

To test whether there were more male or female, and adult or sub-adult EVCs in the overall study area, we examined the sex and age ratios in the road-kill database from 1986 to 2000. Sub-adults were defined as year of young or yearling elk. Chi-square analysis was used to test for a sex and age bias from an assumed 1:1 ratio.

To test whether there was a sex or age class bias in the EVCs with the TCH-park (BNP) elk population, sex and age ratios for the population-were determined. A Chi-square analysis was used to compare these observed ratios with the expected ratios, calculated from the average of spring and fall elk counts on the TCH park (BNP), from 1986 to 2000.

Comparison of Elk Mortality Condition

We tested for differences in condition of elk killed on highways, railways and by predators in BNP. Park research, wardens and veterinary personnel confirmed predator-killed elk. Femur marrow was assayed to measure percent fat content (Neiland 1970); however, we used a dehydrator instead of an oven. Elk mortalities were cross-tabulated by mortality type (highway railway, predator) and condition (i.e., femur marrow fat percentage). We screened data for normality prior to analysis. We tested for independence among categories using ANOVA and Fisher's exact tests (Zar 1999).

Seasonality

To test whether there were seasonal peaks in accidents we assigned EVC records to a season of the year. We used a Kruskal-Wallis ANOVA to test the hypothesis that season had no effect on EVC frequencies. Tukey's HSD multiple range test was used to compare mean values between seasons.

Road Type, Traffic Volume and Elk Abundance
To determine the relative risk posed by each type of highway, elk road-kill frequency was standardized by road length to produce an EVC rate. We used a Kruskal-Wallis ANOVA to test for differences between elk road-kill rates among road types.

We used Spearmans rank correlations to test for a relationship between annual average traffic volume, standardized elk numbers (elk/km) and EVC rate on the TCH Park (BNP) and Highway 93S combined. To test the hypothesis that EVCs differed among these regions, we modeled the effects of relative elk abundance and traffic volume separately. We tested for these effects using two ANCOVAs, one for elk abundance and one for traffic volume. Road type [TCH-park (BNP) and Highway 93S] was included as the categorical predictor. As elk abundance and traffic volume were highly correlated on Highway 93S and TCH park (BNP) (Spearman's rank correlation, both $r > -0.80$, $p < 0.05$), we performed an additional test to tease apart the effect of these variables on EVC rate. We used an ANCOVA to test the effects of elk abundance on EVC rate on the TCH park (BNP) during a period where traffic volumes remained constant. Season (spring and fall) was included as a categorical variable.

Wildlife Vehicle-Collisions
Data Collection
We obtained information on WVCs from the transportation section of Alberta Infrastructure for BNP highways, from 1991 to 1999 and Alberta provincial highways from 1991 to 2000. These WVCs were derived from vehicle accident forms completed by the RCMP. The law requires that motor vehicle accidents with damages totaling more than CD $1,000 (CD $500 up until 1991) or resulting in human injury must be reported to the RCMP.

We chose to use WVC data from the RCMP reports rather than national park warden or provincial ranger reports, as the former were more accurate in reporting the actual time of WVCs. Furthermore, park and provincial WVC data did not include the type of vehicle involved in the collision or severity of the accident, unlike the RCMP reports. One limitation to the RCMP reports was missing information regarding the wildlife species involved in the WVC. For this reason our collision analysis is not species-specific but includes all large mammal wildlife species.

We obtained information on annual traffic volume and classification of vehicle types, on national park roads from Parks Canada (Parks Canada Highway Service Centre, unpublished data) and on provincial roads from the province of Alberta (Alberta Infrastructure, unpublished data).

Temporal Patterns
We used a Spearman's Rank correlation to determine whether WVCs were associated with traffic volumes for each highway from 1996 to 2000. We used traffic volume data from 1999, as they were highly correlated ($R = 0.99$) with traffic volumes from 1997 and 1998. WVCs were classified by the hour of occurrence from the RCMP reports as daylight, dawn, dusk, or darkness periods using sunrise, sunset and twilight time tables, calculated for day 15 of each month (as provided by the Herzberg Institute of Astrophysics, National Research Council of Canada). Dawn and dusk were each 1-hour long. We used a chi-square test to evaluate the null hypothesis that the frequency of WVCs during each time period occurred in proportion to the time available for each period. The significance of each time period was evaluated using Bailey's confidence intervals (Cherry 1996).

We assessed weekly patterns of WVCs by classifying the day of each WVC as weekdays (Monday, Tuesday, Wednesday, Thursday) and weekends (Friday, Saturday, and Sunday). Friday was included as part of the weekend because weekend travel generally begins on Friday. We used a chi-square test to assess the null hypothesis that WVCs occurred equally on weekdays and weekends. The observed values were the number of WVCs that fell within each period. We calculated expected values as the proportion of total observed WVCs relative to the length of each time period.

Mortality by Vehicle Type
We classified the type of vehicle involved in each WVC as a passenger vehicle or large vehicle, for the entire study area from 1991-2000. Passenger vehicles included passenger cars, vans and pick-ups, whereas large vehicles were large trucks (>4500kg), semi trucks, recreational vehicles and buses. We tested the null hypothesis that, WVCs occurred equally between both vehicle classes on Highway 93S and the TCH. We divided the TCH into two sections: TCH-west (west of Sunshine interchange to Yoho National Park west boundary) and TCH-east (east of Sunshine interchange to Highway 40 junction). Observed values were the WVC frequencies that fell within each vehicle class. We calculated the expected values, based on the proportion of each vehicle class on the corresponding road type as determined vehicle-classifying traffic counters (Parks Canada Highway Service Center, unpublished data).

Severity of Wildlife-Vehicle Collisions
We used a logistic regression (maximum likelihood estimates) to predict the probability of occurrence of injury-related motor vehicle accidents as a function of driver safety variables. We developed a motor vehicle collision (MVC) model, which included all types of motor vehicle accidents within the study area and a WVC model, which included only wildlife-related accidents. Five independent variables were included in the model: *darkness* (day vs. dark-dawn-dusk); *type of accident* (wildlife vs. other); *posted speed* (90km/h vs. 110km/h); *vehicle involved* (passenger car vs. large vehicle); and *surface condition* (dry vs. slush- snow-ice). RCMP officers classed accidents at three severity levels: fatal, injury related or property damage. Since fatal MVCs were relatively few ($n = 47$), they were included with injury-related accidents. Indicator or dummy variables were created for each categorical variable with one reference comparison variable.

We used the log-likelihood ratio test (Hosmer and Lemeshow 1989) to determine the overall significance of each model. We assessed the improvement of fitted models over null models according to the difference in (-2) log-likelihood ratios. Significance ($p \leq 0.05$) of explanatory variable coefficients was based on chi-square tests of Wald statisitcs (Hosmer and Lemeshow 1989). Standardized effect coefficients were not calculated; however, we multiplied logistic regression coefficients by the standard deviation of the respective variables within the model. We called this parameter the standardized estimate coefficient. Interpretation of logistic regression coefficients was made in terms of statements about odds ratios. We also included cross-validation classification accuracies for each model. Prior to performing the regression analysis we tested potential explanatory variables for multicollinearity (Menard 1995).

Data were analyzed for all analyses using Microsoft Excel, SPSS version 7.5 (SPSS 1996) and the Statistica™ kernel release 5.5 statistical package (Statsoft 2000). All analyses assume data are independent and drawn at random; however, we caution that the efficiency of accident reporting between seasons, years and geographical location may vary. We screened all data for outliers and normality prior to each analysis. Chi-square analyses assume that equal sampling effort was applied to each category. The sample size in each analysis was different because some vehicle collision records did not contain information for all variables. We assumed that the number of wildlife collision records collected and used for analysis provided a representative sample of the total wildlife collisions in the study area.

Results and Discussions

Error Reporting

National Parks and Alberta Province
The average reporting distance error between the national park and the provincial collaborators was significantly different ($t = 2.34$, $p < 0.05$). The average reporting error was almost twice as large in the national parks (mean = 618 ± 993 m) compared to the province (mean = 364 ± 371 m) (table 1). The standard deviation was highest for national park reporting (=993m) compared to provincial reporting (=371m). The overall average reporting error in the study area was 516 ± 808m.

Table 1
Average distance reporting errors from all road-kill records from mountain national parks (Banff, Kootenay, Yoho) and the province of Alberta (1998-2001).

GROUP	*N*	Mean error (m)	Minimum (m)	Maximum (m)	± SD (m)
MOUNTAIN NATIONAL PARKS					
National Park Reporting (Occurrence reports and mortality cards)	138	618	0	6500	993
ALBERTA PROVINCE					
Alberta Province Reporting (Volker-Stevin and Alberta Natural Resources)	95	364	0	1700	371
TOTAL (National parks & province)	233	516	0	6500	808

It is difficult to compare the mean reporting errors between the mountain national parks and the Alberta province since their methods of reporting were different, and the degree of interaction between project personnel and reporters varied between parties. The high standard deviation associated with national park reporting can be explained by the quantity and churn of personnel within the national parks. Volker-Stevin had the same five or six collaborators reporting collisions, while the national parks had over 50 reporters who changed seasonally over the study period. Methods of reporting, degree of interaction between personnel and reporters, quantity of reporters, and attitude of reporters will all determine the success, and accuracy of this type of project.

Royal Canadian Mounted Police
The average distance reporting error of the RCMP WVC records was 2154 ± 1620m (n = 26 paired records). This surprisingly large RCMP reporting error is likely to be a result of the method of reporting and eventual designation of road-kill location by Alberta Infrastructure. The transfer of data from the field-reported record, referenced to landmarks in the field, followed by their conversion into standard kilometre postings, undoubtedly results in greater error being added to the definitive road-kill location. Nonetheless, these data have been used in the past to identify WVC hot spots, other site-related characterizations of road-kill occurrences and/or planning mitigation signage locations (Kerr 1997; Seaby 1997, 1998). Caution should be taken before using these data, particularly if spatial analyses are carried out. The spatial error is sufficiently large that resulting analyses will not be robust, nor provide useful information for mitigation planning.

The data we collected on the true WVC locations and average reporting error, have allowed us to obtain site-specific information on WVCs to be used in future analyses of local-scale factors influencing wildlife-vehicle accidents. Information on the average reporting error will allow the use of the much larger BNP mortality database (1981-present) in coarse-scale analyses of factors influencing WVCs in the Banff-Bow Valley.

Elk-Vehicle Collisions
Sex and Age
Within the overall study area there were significantly higher numbers of female EVCs than male EVCs (χ^2_1 = 71.0, n = 586, p < 0.010). More adult elk were involved in EVCs than sub-adults (χ^2_1 = 54.9, n = 569, p < 0.001).

There were higher quantities of female EVCs compared to male EVCs on the TCH park (BNP) between 1986-2000. This female bias can be explained by there being fewer bulls in the Bow Valley population (Flook 1970).

The overall sex ratio of EVCs was significantly different from that found in the Bow Valley population, and highly skewed towards greater male mortality during the 15-year period (χ^2_1 = 62.1, n = 147, p < 0.001). Different patterns of movement between female and male elk can explain the higher probability of male elk becoming involved in a vehicle collision. Woods (1991) showed more bulls migrate than females as a whole in the Bow Valley population. During the rutting season males then move back into the rutting grounds within the valley to access more mates (Woods 1991). Romin and Bissonette (1996b) and Joyce and Mahoney (2001) found a similar male-biased relationship with deer- and moose-vehicle collisions, respectively.

The number of EVCs involving sub adults on the TCH park (BNP) was comparable to the number of EVCs involving adults*;* whereas, the overall age ratio of EVCs was significantly different from that found in the population and highly skewed towards greater sub-adult mortality over the entire time period, 1986 to 2000 (χ^2_1 = 160.5, n = 224, p < 0.001). This could be related to driver behaviour, as a driver will swerve to miss the adult cow only to hit her calf following close behind, as noted by Joyce and Mahoney (2001) with moose-vehicle collisions. Further, sub-adult elk do not have experience in crossing roads and probably cross the road less cautiously than adult cows. Dusek *et al*. (1989) also showed a greater proportion of yearling, male white-tailed deer involved in collisions than that found in the population.

Comparison of Elk Mortality Condition
Between 1990 and 1998, 397 elk carcasses were collected in BNP that were killed on highways (n = 102), railway (n = 133), and by predators (n = 162). There was a significant effect of elk condition on the three types of mortality (Kruskal-Wallis test, $F_{2,397}$ = 9.45, p < 0.0001). Percent marrow fat content of highway- and railway-killed elk was not significantly different, but both had a significantly greater percentage fat content than predator-killed elk (Tukey's HSD test, p < 0.05). This suggests that motor vehicles on highways, and trains on railways, do not discriminate based on the condition of elk; however, predators apparently do by taking individuals in poorer-than-average condition. O'Gara and Harris (1988) found the opposite results of our study, i.e., predators such as cougars and coyotes killed prime-aged deer, and deer killed by automobiles were in poor condition.

Seasonality

Season had a significant effect on the number of EVCs (Kruskal-Wallis test, $F_{3,44} = 3.48$, p = 0.025) as displayed in figure 2. There were significantly more EVCs in fall compared to spring, summer, and winter (Tukey's HSD test, p = 0.003 and p = 0.010, respectively). This can be largely explained by the seasonal population trends for elk in the Rocky Mountains that occurred during the study period. Elk numbers on average increased more than two times from spring to fall during the study period (Parks Canada, unpubl. data). Previous studies have documented peak mortalities with ungulates in autumn (Hubbard et al. 2000; Puglisi et al. 1974; Romin and Bisonette 1996b; and Groot and Hazebroek 1996), which are associated with an increase in movements during the hunting and breeding periods.

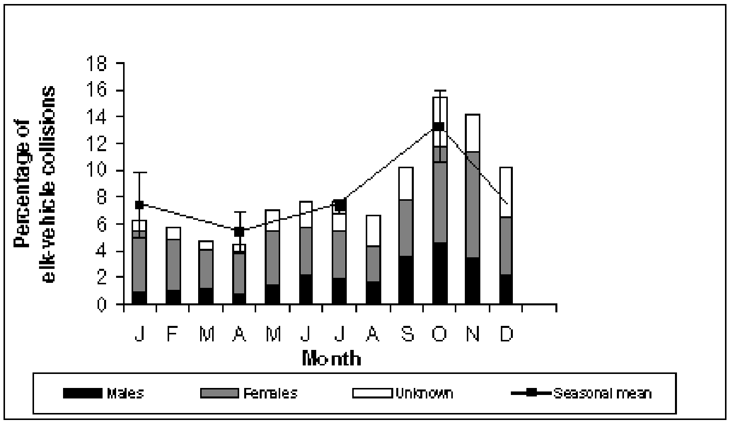

Fig. 2. The seasonal distribution of elk-vehicle collisions in the Canadian Rocky Mountains, 1985 to 2001 (*n* = 770). Seasonal means are shown as connected points; bars indicate ± SE.

Road Type, Traffic Volume and Elk Abundance

EVC rates were significantly different between each road type (Kruskal-Wallis test, $F_{3,44} = 19.33$, $p < 0.0001$). They were significantly higher on the TCH province compared to TCH-park (BNP), TCH park (YNP) and Highway 93S (Tukey's HSD test, $p = 0.002$, $p < 0.0002$, and $p < 0.0001$, respectively). The TCH park (BNP) had a significantly higher rate of EVCs than Highway 93S ($p = 0.023$).

Figure 3 below shows the number of EVCs for each year, together with the average number of elk surveyed per kilometre and the annual average daily traffic volume for the TCH park (BNP) and Highway 93S. As traffic volume increases, the mean number of elk per kilometers and the number of EVCs decrease (Spearman's rank correlation, between all variables r>0.9, p<0.0001).

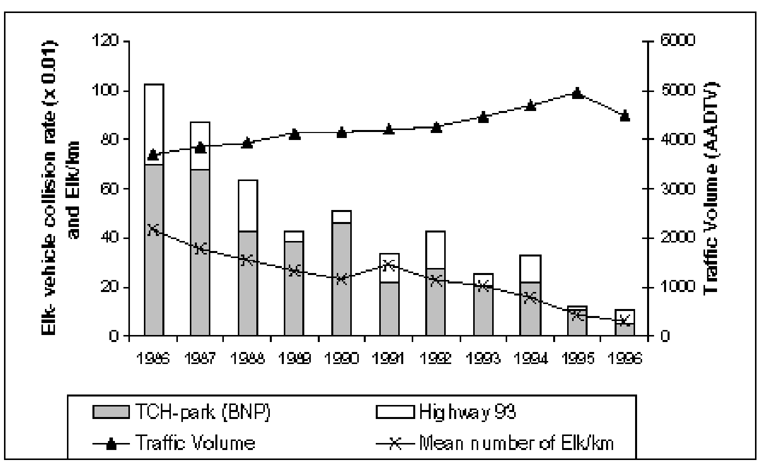

Fig. 3. Standardized number of elk-vehicle collisions annually, with annual average daily traffic volume and estimated standardized elk abundance along Highway 93 and the Trans-Canada Highway park in the Central Canadian Rocky Mountains, 1986-1997.

It is common knowledge that the incidence of wildlife-vehicle collisions is dependant on traffic volume and relative abundance of wildlife species (Fahrig *et al*. 1995, Boulanger 1999, Philcox *et al*. 1999, Romin and Bissonette 1996b). However, to understand how these variables interact to determine EVC rates on different road types is much more complicated. Elk collision rates differed between road types in our study, where those having the highest traffic volumes had the highest kill rates. Therefore, it was an interesting correlation to find that as traffic volume increased, the mean number of elk mortalities per kilometers decreased on highway 93S and the TCH park (BNP). The decline in elk population numbers throughout the 1980's drove this relationship. This relationship has also been documented by Fahrig *et al*. (2001) and Boulanger (1999), which suggested that highway mortality rates can be used as an indicator of population trends even when highway traffic volumes are changing.

The model describing the effect of standardized elk abundance on EVC rate on Highway 93S and TCH park (BNP) was significant (ANCOVA, $F_{3,18}$=18.19, p < 0.0001, r^2 = 0.75). There was a significant interaction between road type and elk abundance ($F_{2,18}$ = 15.5, p < 0.0001). There was a positive relationship between EVC rate and elk abundance, which was more significant on the TCH park (BNP) than on Highway 93S.

The model describing the effect of traffic volume on EVC rate on Highway 93S and TCH-park (BNP) was significant (ANCOVA, $F_{3,18}$ = 27.04, p < 0.0001, r^2 = 0.82). There was a significant main effect of road type ($F_{2,18}$ = 10.5, p < 0.01), with the TCH having more EVCs than Highway 93S. There was also a significant interaction between traffic volume and road type ($F_{2,18}$ = 24.4, p < 0.0001) indicating that the relationship between traffic volume and EVC rate depends on road type. The negative relationship between EVC rate and traffic volume, was more extreme on Highway 93S compared to TCH-park (BNP) where traffic volumes were significantly higher (t = -26.62, n = 11, p < 0.0001).

The model describing the effect of elk abundance on the EVC frequencies when traffic volume remained constant was significant (ANCOVA, $F_{3,18}$ = 28.70, p < 0.0001, r_s = 0.82) indicating that elk abundance influences EVC rate independent of traffic volume. There was a significant interaction between season and elk abundance ($F_{2,18}$ = 24.19, p < 0.0001), indicating that the relationship between the EVC frequencies and elk abundance differed between the two seasons. The rate of increase of EVCs with respect to elk abundance was greater during the fall season when elk abundance numbers were higher (t = -2.09, n = 16, p = 0.045).

The relationships between EVC rate, traffic volume and elk abundance were the same on both road types, but the degree of interaction differed between them. As traffic volumes increased throughout the study period the EVC rate decreased to a lesser degree on the TCH. Further, the positive relationship between EVC rate and abundance levels was more prominent for the TCH park (BNP). The sheer numbers of traffic on the TCH compared to Highway 93S increased the probability of elk-vehicle collisions on this highway. More research is needed to determine if at some point the increased traffic volumes will result in animals avoiding the road and thus reducing collision rates. Long-term trends in population abundance, traffic volumes and collision rates can help to tease apart this phenomenon.

When traffic volumes (spring vs. fall) and confounding variables associated with the study area were held constant, collision rates were significantly higher in the fall when population numbers increased due to the addition of the spring calf cohort. Romin and Bissonette (1996b) also report a seasonal decrease in deer mortality due to reduced population numbers after harsh conditions in winter. As noted above fall peaks have been documented in ungulate mortalities (Romin and Bissonette 1996b, Hubbard *et al.* 2000, Puglisi *et al*. 1974) due to an increase in movement patterns associated with the breeding season and hunting season. Elk-vehicle collision trends followed fluctuations in population abundance, independent of increasing or level traffic volumes, however behaviour associated with life history activities of elk, e.g. breeding, and migration, may have also influenced year-round road-kill levels and composition.

Wildlife-Vehicle Collisions

Temporal Patterns

The frequency of WVCs for each hour from 1991-2000, together with the average hourly traffic volume for 1999 is shown in figure 4. The frequency of hourly WVCs was not correlated (R = -0.25, n = 24, p = 0.225) with average hourly traffic volumes. This result suggests there must be another factor influencing the occurrence of WVCs during the 24-hour day.

We rejected the null hypothesis that WVCs occurred equally in all light categories (χ^2_3 = 258.10, n = 1706, p < 0.0001). Light, dark and dusk categories had expected values that fell outside Bailey's 95 percent confidence intervals (Cherry 1996). Dark and dusk categories had significantly more accidents than expected, while light had significantly fewer accidents than expected. Fifty-nine percent of WVCs occurred during darkness and dusk. Joyce and Mahoney (2001) have shown this same temporal pattern in moose-vehicle collisions in Newfoundland, with 75 percent of all accidents occurring between sunset and sunrise.

The U.S. National Highway Traffic Safety Administration reports that at night you can only see 160 feet ahead of your vehicle resulting in less time to avoid a crossing animal. In addition, humans lack the ability to distinguish similarly coloured objects at night, and glare from oncoming headlights bleach human visual receptors, temporarily blinding drivers (Hess *et al*. 1990), contributing to the likelihood of a wildlife collision at night.

We rejected the null hypothesis that MVCs occurred equally on weekdays and weekends ($\chi^2_1 = 23.07$, $n = 1805$, $p = 0.0001$). More accidents than expected occurred on weekends than weekdays. The most logical explanation for this result would be the increased traffic volumes evident on weekends (Parks Canada, unpublished data) as more people travel at this time. Alberta Transportation (2001) also reported Friday as being the most collision-prone day of the week, perhaps due to motorist behaviour, such as fatigue, which reduces reaction time to a dangerous situation.

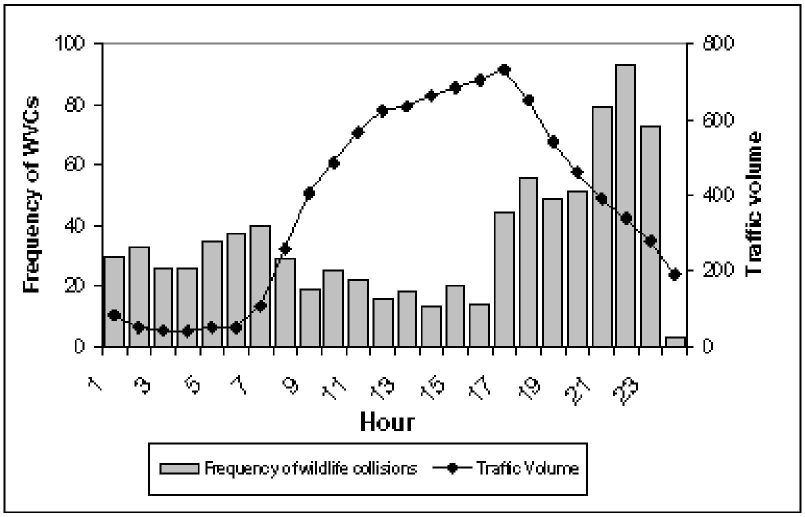

Fig. 4. Relationships between frequencies of hourly wildlife-vehicle collisions and average hourly traffic volume on the Trans-Canada Highway in Banff National Park and the province of Alberta and Highway 40 from 1991 to 2000.

Mortality by Vehicle Type

Passenger vehicles caused 8 percent of the WVCs; whereas, 14 percent involved large vehicles. We rejected the null hypothesis that WVCs occurred equally among vehicle classes on Highway 93S ($\chi^2_1 = 65.86$, $n = 187$, $p < 0.0001$) and the TCH-west section ($\chi^2_1 = 7.88$, $n = 42$, $p = 0.005$). On both highways there were more large vehicles causing WVCs than expected, and fewer WVC than expected were caused by passenger vehicles. WVCs occurred in proportion to what was expected on the TCH-east ($\chi^2_1 = 3.63$, $n = 546$, $p = 0.057$). Caution should be used when using these reported frequencies, as WVCs reported by passenger vehicles are much higher than those reported by large commercial vehicles, because the damage to a larger vehicle is minimal and therefore goes unreported. Nonetheless, more WVCs involving large vehicles than expected occurred on two sections of highway even though counts would have been conservative. Larger vehicles have a much longer stopping distance due to the weight of the vehicle (Alberta Transportation 2001), and it would be unsafe to swerve out of the way of a crossing animal.

Severity of Wildlife-Vehicle Collisions

We used 2,619 accident records in the MVC model, of which 506 were injury-related accidents and 41 were fatalities. There were 27 percent ($n = 719$) of accidents that were wildlife related, of which 57 were injury related and none was fatal.

The MVC and WVC model were both statistically significant with $p < 0.001$ and $p < 0.001$, respectively. The variance explained by the models and overall cross-validation accuracies were highest for the MVC model ($R^2 = 0.086$; 80.26%), followed by the WVC model ($R^2 = 0.062$; 93.05%). Accident type was most important in explaining severity in MVCs. Injury-related accidents were 87 percent (odds ratio = 0.1257) less likely to occur in a wildlife collision relative to other types of collisions. Lo (2003) reports that only three percent of WVCs were injury related, while 0.05 percent were fatal in all wildlife-vehicle crashes on rural roads in Alberta in 2001. Human injury or fatality in a wildlife-vehicle collision may be low relative to other types of collisions; however, injury and fatality for the animal is almost certain, and the economic costs are extreme. Joyce and Mahoney (2001) report an annual economic loss of $3,850,000 (CD) from moose collisions alone in Newfoundland.

Further, injury-related accidents were 69 percent (odds ratio = 0.3125) less likely to occur in slush, snow or ice conditions relative to dry conditions. Likewise, Alberta Transportation (2001) reports that the majority (70.9%) of all casualty collisions occurred when surface conditions were dry. This is probably due to motorist behaviour in different weather conditions. As road conditions improve drivers tend to speed, increasing the likelihood of being involved in a motor/wildlife-vehicle collision. Speeding is one of the most prevalent factors contributing to traffic crashes. Speeding reduces a driver's ability to steer away from objects in the roadway, and extends the distance necessary to stop a vehicle (as provided by the National Highway Traffic Safety Administration, U.S Department of Transportation).

The only significant factor in the WVC model was type of vehicle. Injury-related accidents are 3.65 times more likely to occur when driving a passenger vehicle relative to larger vehicles. Alberta Transportation (2001) also reports that passenger cars are involved in 76 percent of the total casualty collisions. Smaller vehicles have less structure and size to absorb crash energy, so injurious forces can easily harm the occupants in crashes.

Conclusions and Recommendations

The long-term trend and prospects are for increasing traffic volumes on the TCH and other primary roads in the parks. Our findings link increasing traffic volumes with a decreasing elk population, which underscore the need for more information on the factors contributing to ungulate-vehicle collisions before mitigation schemes are planned, designed or implemented. Mitigation implemented based on wildlife-vehicle collision data analyses should be rigourously monitored to determine how effective measures are at reducing road-kills.

Wildlife-vehicle collisions tend to occur more than expected, at night, on dry road conditions and by larger vehicles. The ability for a motorist to avoid a collision is reduced in all these situations due to reduced visibility and increased stopping distances. By decreasing the speed, the motorist can compensate for the increased probability of being involved in a collision. Wildlife managers should enforce current speed limits and consider decreasing night driving speeds for all vehicles.

Spatial road-kill data can aid in determining location of mitigation measures, e.g., wildlife signage and crossing structures. Patterns of WVCs can be valuable in devising mitigation based on specific hour of day or season when collision frequencies are highest. Determining what individuals within a population are most susceptible to road-kills can help assess the demographic impacts of wildlife collisions. The type of vehicle, such as passenger vehicles and trucks, involved in collisions can help target public awareness and education campaigns. Factors contributing to WVCs, such as traffic volumes and elk abundance, can help managers predict long-term viability of wildlife populations with incurring road mortality. In addition, WVC intensities on different road-types can help managers identify and prioritize road-types for mitigation.

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Biographical Sketches: Kari Gunson is a wildlife research biologist who is currently subcontracted by Parks Canada. She has been a researcher with the Trans-Canada Highway Research Project, which looks at road effects on wildlife populations in the Banff-Bow Valley and the surrounding national and provincial parks, since 1999. She is a graduate from the University of Calgary, Alberta and has a master's degree in conservation biology from the University of Capetown, South Africa. Her research in South Africa used Landscape Ecology and resource economics in a GIS to determine the economic importance and sustainability of use of wetland plant resources within the local community.

Tony Clevenger is a wildlife research ecologist at the Western Transportation Institute, Montana State University (Bozeman, Montana) and has been studying road effects on wildlife populations in the Banff-Bow Valley and the surrounding national and provincial parks since 1996. Tony is a graduate of the University of California, Berkeley, and has a master's degree in wildlife ecology from the University of Tennessee, Knoxville, and a doctoral degree in zoology from the University of León, Spain. He is currently a member of the U.S. National Academy of Sciences Committee on Effects of Highways on Natural Communities and Ecosystems.

Bryan Chruszcz completed his B.Sc. in biology at Queen's University in Kingston, Ontario, and his M.Sc. in ecology at the University of Calgary. His M.Sc. research examined the foraging, roosting and thermoregulatory ecology of bats in the badlands of southeastern Alberta and in eucalypt forests in Queensland, Australia. Bryan has spent the past four years working as a wildlife ecologist for the Trans-Canada Highway Wildlife Research Project in Banff National Park. Bryan is currently working as a wildlife ecologist and consultant on a variety of projects across western North America.

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A MATHEMATICAL MODEL FOR ESTIMATING WILDLIFE MORTALITY ON ROADS, AND ITS IMPLICATIONS FOR MITIGATION AND MANAGEMENT

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Abstract
In an attempt to understand the effects that roads were having on wildlife in Saguaro National Park, weekly wildlife mortality surveys were conducted from 1994-1999. From our weekly surveys, and additional data we collected, we developed a mathematical model to estimate the average annual number of animals killed on roads in and adjacent to the Park. This model accounts for variables (i.e., observer error, scavenging, episodic events, and taxonomic differences in activity periods) that we knew existed and affected the interpretation of our weekly survey data. We believe the model is broadly applicable given certain classes of data. Our model is very conservative in that effects not captured by the data or not included in the model (such as animals that are hit, but killed off the road) would tend to increase the total mortality figures. Similarly, estimates of model parameters based on the data also tend to lower the mortality estimate. Nevertheless, the model more than doubled our previous estimates of annual roadkill in the Park. Based on our model, we estimate that about 51,000 animals are killed annually on the 50 miles of roads that lie in or adjacent to both districts of Saguaro National Park, including about 17,000 amphibians, 27,000 reptiles, 1,000 birds and 6,000 mammals. The implications of these numbers to local wildlife populations varies, but some species (i.e., the Colorado River toad) appear to be impacted at a population level. Along with spatial analysis of the data, these figures enabled us to identify locations and types of mitigation that might be most useful to wildlife in the Park.

Biographical Sketch: Natasha Kline is the wildlife program manager at Saguaro National Park in Tucson, Arizona, where she has worked for ten years. She has also worked as a biologist for the Air Force, the Fish and Wildlife Service, and at other national parks. Natasha has a B.S. in zoology and an M.S. in biology.

OVERVIEW OF ANIMAL DETECTION AND ANIMAL WARNING SYSTEMS IN NORTH AMERICA AND EUROPE

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Abstract: The purpose of animal detection and animal warning systems is to prevent or reduce the number of animal-vehicle collisions. These systems are specifically aimed at large animals (e.g., ungulates) that can cause human death, injury and property damage. Animal detection systems detect large animals before they enter the road and then warn drivers that a large animal is on or near the road at that time. Animal warning systems detect vehicles and then warn the animals through a variety of audio and visual signals. This paper lists all animal detection and animal warning systems known to the authors in September 2003. We identified 27 locations where systems are or have been in place in North America and Europe. In addition, we identified 20 sites for which an animal detection or animal warning systems are planned. We described the main characteristics of the systems and reviewed them with respect to operation and maintenance. We conclude that animal detection and animal warning systems have the potential to be an effective mitigation tool. However, further research and development is needed before they can be applied on a wide scale.

Introduction

Animal-vehicle collisions affect human safety, property and wildlife. In the United States more than 90 percent of animal-vehicle collisions involve deer (Hughes et al. 1996), and the total number of deer-vehicle collisions was estimated at more than one million per year (Conover et al. 1995). These collisions were estimated to cause 211 human fatalities, 29,000 human injuries and over one billion dollars in property damage a year (Conover et al. 1995). Similar numbers are available from Europe (excluding Russia) where the annual number of collisions with ungulates was estimated at 507,000. These collisions were estimated to cause 300 human fatalities, 30,000 human injuries and over one billion dollars in material damage per year (Groot Bruinderink and Hazebroek 1996). These numbers are likely to have increased even further over the last decade (Hughes et al. 1996; Romin & Bissonette 1996; Anonymous 2003a). In most cases, the animals die immediately or shortly after the collision (Allen and McGullough 1976). In some cases, it is not just the individual animals that suffer. Some species are also affected on the population level and may even be faced with a serious reduction in population survival probability (e.g., van der Zee et al. 1992; Huijser and Bergers 2000; Proctor 2003). In addition, in some species a monetary value is lost once an animal dies (Romin and Bissonette 1996; Conover 1997).

Historically animal-vehicle collisions have been addressed by putting up signs that warn drivers of potential animal crossings. In other cases, wildlife warning reflectors or wildlife fences have been installed to keep animals away from the road (e.g., Clevenger et al. 2001). However, conventional warning signs appear to have only limited effect because drivers are likely to habituate to them (Pojar et al. 1975), wildlife warning reflectors may not be effective (Reeve and Anderson 1993; Ujvári et al. 1998), and wildlife fences isolate populations. In some selected areas wildlife fencing has been combined with a series of wildlife crossing structures (e.g., Foster and Humphrey 1995; Clevenger et al. 2002). In most cases however, such crossing structures are limited in number and width, mostly because of their relatively high costs. In this paper we review a relatively new alternative to wildlife crossing structures: animal detection and animal warning systems that are located in the right-of-way. Vehicle-based animal detection systems (e.g., Bendix 2002; Cadillac 2003) are not included in this paper. Animal detection systems detect large animals as they approach the road. When an animal is detected, signs are activated that warn drivers that large animals may be on or near the road at that time. Animal warning systems operate on a slightly different principle as they detect vehicles, not the animals. When a vehicle is detected the animals are alerted through a range of audio and visual signals from stations placed in the right-of-way. This paper lists all animal detection and animal warning systems in the world known to the authors as of September 2003. In addition, we describe the main characteristics of the systems and we review them with respect to operation and maintenance.

Methods

Information on the existence of animal detection and animal warning systems in the right-of-way is not well documented at this time. Our list of animal detection and animal warning systems is based on previous overviews (Farrell et al. 2002; Robinson et al. 2002), research reports, searches on the Internet, newspaper articles, press releases, and interviews with researchers, system manufacturers and integrators, and employees from transportation agencies. Our overview distinguishes between locations that have an operational system, an installed system that is not operational yet, a dismantled system, and locations for which a system is planned (situation September 2003).

We classified the systems into two main categories: area-cover systems and break-the-beam systems. We also identified three unique systems. We described each system with respect to the following parameters: (1) location, (2) target species, (3) technology, (4) system vendor, (5) system installer, (6) road length covered by the sensors, (7) presence or absence of adjacent fencing, (8) system costs, (9) installation costs, (10) whether or not data are available on operation and maintenance, driver behavior, and number of animal-vehicle collisions, (11) month and year of installation, and (12) period of operation. Finally, we discuss additional issues that may affect the operation and maintenance of the systems.

Results

System Numbers and General Location

We identified 27 locations with an animal detection or animal warning system. Nine of these sites are located in North America, eight sites with an animal detection system, and one site with an animal warning system (fig. 1). As far as we know, only four of these sites have a system that is currently in operation (situation September 2003). On three sites a system has been installed, but the systems are not operational yet. On the remaining two sites the systems have been dismantled. In Europe we identified 18 locations with animal detection systems (fig. 2). As far as we know, 17 of them have a system that is currently in operation. The system on the remaining site has been dismantled. In addition to the 27 sites mentioned above, we have identified 5 sites in North America and 15 sites in Europe for which an animal detection system has been planned. The location of animal detection and animal warning systems in North America is shown in figure 1..

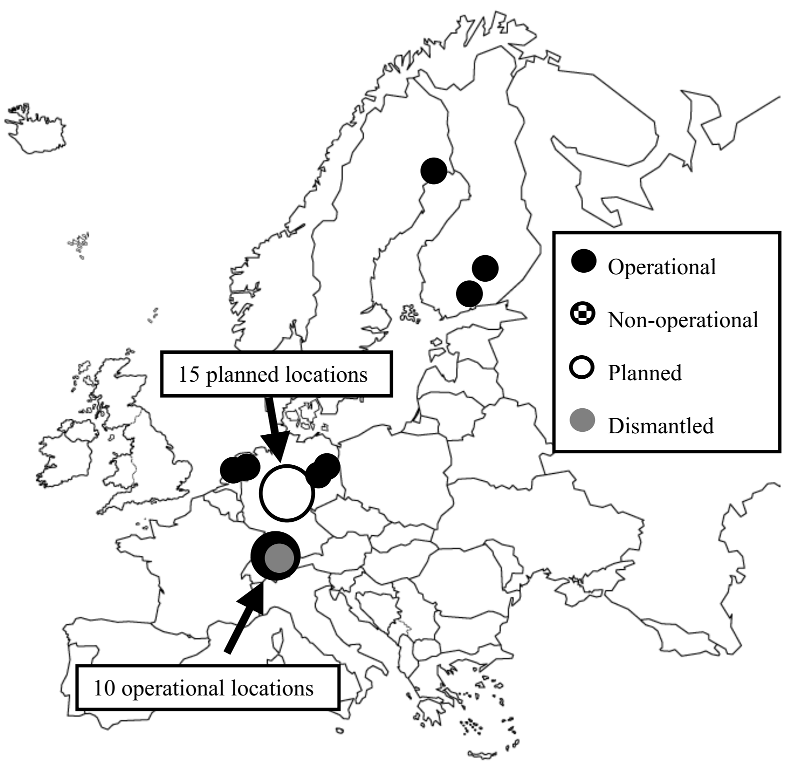

Fig. 1. The location of animal detection and animal warning systems in North America.

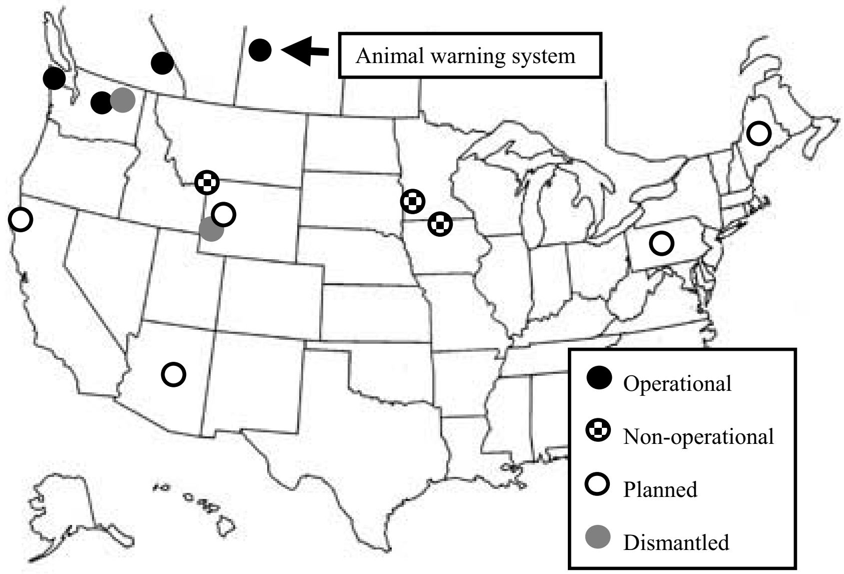

Fig. 2. The location of animal detection systems in Europe.

Existing Systems
The main characteristics of existing systems are listed in table 1. More details on the area-cover systems (section a. through e.), break-the-beam-systems (section f. through m.), and three unique systems (section d., n. and o.) are described below.

a. Seven Locations, Switzerland
Kistler (1998) and Tschudin (1998) reported on a study that covered seven locations in Switzerland. The systems were supplied by Calonder Energy AG in Dietikon, Switzerland. Each system consisted of a series of passive infrared sensors. The sites, their installation date, the width of the crossing area and number of sensors installed, are listed in table 2. The passive sensors were designed to detect ungulates such as roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*) within a 30-100m radius.

Table 1.
Main characteristics of area-cover systems (a-e), break-the-beam-systems (f-m), and three unique systems (d, n and o). Evaluation: information available on: O = Operation and maintenance, V = Vehicle speed, C = Animal–vehicle collisions. CH = Switzerland, D = Germany, NL = The Netherlands, S = Sweden. Present = September 2003.

ID #	Location	Target species	Distance covered	Fence	Cost system	Cost Install.	Eval-uation	Installed	Operational
a	7 loc., Switzerland	Roe deer, red deer	50-200m	No	$11,500	?	OVC	'93-'96	'93/'96-present[1]
b	Box, Uusimaa, Finland	Moose	220m	Yes	$60,000	$40,000	OV	Sep '96	Dec '96-present
c	Mikkeli, Finland	Moose	90m	Yes	$40,000	$30,000	O	'99	'99-present
d	Nugget Cany., WY, USA	Mainly mule deer	92m	Yes	$200,000[2]	?	OV	1 Dec '00	8 Dec '00-21 May '01
e	Kootenay NP, BC, Canada	White-tailed deer	1,000m	No	?	?	O	Jun '02	Sep '03-present
f	4 loc. CH; 2 loc. D	Roe deer, red deer	?		±$20,000[3]		?	'98-'01/ '02?	?
g	2 loc. NL	Roe deer, red deer, wild boar	200-250m	Yes	±$50,000[4]		O	'99	in operation
h	Rosvik, S	Moose	100m	Yes	±30,000[5]	?	O	'99	'00-present
i	Colville, WA, USA	Deer, elk	402m	No	$9,000[6]	$3,000	O	20 Jun '00	Taken down spring '02
j	Marshall, MN, USA	White-tailed deer	1,609m	No	$50,000	$7,000[7]	O	Jun '01	Turned off Nov '01
k	Wenatchee, WA, USA	Deer	213m	No	<$40,000[8]	?	O	Oct '02	Oct '02-present
l	Yellowstone NP, MT, USA	Elk	1,609m	No	$350,000[9]	$60,000	O	Oct/ Nov '02	Not operational
m	South Bend, IN, USA	White-tailed deer	9,654m[10]	No	?	?	O	Apr '02	Not operational
n	Sequim, WA, USA	Elk	4,827m	No	$60,000[11], $13,000[12]	?	O	Apr '00	Apr '00-present
o	Harris, SK, Canada	Mostly Mule deer	5,000m	No	$36,000[13]	?	O	Apr '02	Apr '02-present

[1] All in operation except Marcau site (road work Aug '97)
[2] Incl. operat. & maint., research, excl. WYDOT salaries
[3] In Switzerland
[4] Incl. installation and fence
[5] Excl. ± $70,000 for electricity
[6] Excl. signage, batteries
[7] Excl. salariesTable 2. Main characteristics of the seven systems located in Switzerland (Kistler 1998).
[8] Incl. research, design, installation
[9] Including research and development
[10] Divided over 6 sections (1 mile each)
[11] For equipment
[12] For herding and collaring
[13] Excl. in kind contributions

Table 2.
Main characteristics of the seven systems located in Switzerland (Kistler 1998).

Location	Installed	Distance covered (m)	Sensors (n)
Warth	February 1993	150	7
Soolsteg	November 1996	80-90	6
Val Maliens	May 1993	150	5-8
Marcau	May 1993	50-60	2
Schafrein	December 1995	80	5-6
Duftbächli	December 1995	30-50	4
Grünenwald	December 1995	190-200	4-6

The sensors were installed in a 20-30m wide zone on both sides of the road. Once an animal was detected LED signs with a deer symbol were activated to alert the drivers. Once activated, the signs stayed on for 45 secs. Five of the sites also had an LED sign with an enforceable maximum speed limit (40km/h). The seven systems were only activated during the night. A time clock and light sensor switched the systems on and off automatically. The rationale was that human activities during the daytime would cause a high number of false detections. In addition, the sensors were relatively sensitive to differences in temperature, which occur frequently during the day. There were no fences or other barriers specifically erected for wildlife on either side of the crossing areas. However, most locations had support walls, steel nets and guardrails just before and after the crossing areas, which helped funnel the wildlife through the crossing area (Kistler 1998). Depending on the site, local game wardens or road maintenance personnel checked the system every three to five days, once a week, or once every two weeks. Warm engines of passing vehicles, and falling branches, especially with strong winds, caused false detections. Broken sensors, loss of power due to snow covered solar panels, and broken lamps in the warning signs caused additional problems.

b. Box, Finland
This system consists of microwave radar sensors that were designed to detect moose (*Alces alces*) in a 220-m-wide gap in a several kilometers-long moose-proof fence along Hwy 7, near Box, between Helsinki and Porvoo, about 20km southwest from Porvoo, Uusimaa, Finland (Taskula 1997; Muurinen and Ristola 1999; Pers. com. Kari Taskula, Sabik). Sabik Ltd, Finland, supplied and installed the system. Five poles were placed on each side of the road 5-20m from the pavement. Each pole had two sensors that faced away from the road. The sensors were designed to detected large animal movements up to 50m in distance within a 60° horizontal angle. When a large animal was detected, LED message signs with a moose symbol were turned on. The signs warned drivers about the presence of large animals on or near the road remaining lit for two to three minutes after being triggered by an animal. The message signs were located 150-200m before the crossing area. Detection of a large animal also activated a video camera and recorder. The camera turned and zoomed toward the detection area. The images were used to verify the presence of large animals and to evaluate the reliability of the system. The system records start and end time of every detection event of all detectors, the status of the signs (on or off), and invalid detections. The data are stored in a file that is downloaded on a daily basis from a remote location through a modem and a user interface program. It is also possible to open the modem connection through the user interface program and to monitor the system real time. The system was installed in September 1996, but tests and modifications to the system took another three months. To distinguish moose from other moving objects such as rain or rain spray, the system was programmed to only detect objects moving towards the sensors at a speed greater than 0.8m/s. The sensors were placed 3m above the ground, and their vertical angle was modified to reduce false detections caused by small animals such as rabbits and birds. Furthermore, the signal had to be contiguous for at least 0.5 secs. Rain and variations in air pressure also caused false detections. This was mitigated by attaching metal eaves to the detectors and by filtering out rain noise at the interface. In addition, 16 passive infrared detectors and one rain detector were integrated into the system to help filter out false detections (Taskula 1999). The microwave detectors were automatically switched off if multiple consecutive detections were reported after rain was detected. The system operated on infrared detectors only under those conditions. After the system became fully operational in mid-December 1996, some false detections continued to occur (Taskula 1999; Pers. com. Kari Taskula, Sabik). In spring when the snow melted and the water warmed on the pavement, spray from passing vehicles triggered the system. After improvements were made in 1997-1998 most of the problems disappeared, and false detections became rare. However, there are still a few false detections in spring.

c. Mikkeli, Finland
This system is similar to the one described above. It is located along Hwy 5, between Lahti and Mikkeli, about 25km southwest from Mikkeli, Finland (Pers. com. Kari Taskula, Sabik). The detector poles were located 5m

from the pavement. If an agreement had been reached with a local landowner, the detectors would have been placed 15-20m from the roadside. This would have eliminated false detections caused by rain spray from passing vehicles. Gaps in the fence at side roads and the relatively short width of the crossing area increase the chance that moose wander off along the road in the right-of-way, instead of crossing the road at a straight angle. However, only one such event has ever been documented (situation September 2003).

d. Nugget Canyon, Wyoming, USA
The Flashing Light Animal Sensing Host (FLASH) was designed to detect mule deer (*Odocoileus hemionus*) and consisted of a series of infrared sensors placed at 17-19m intervals on both sides of Hwy 30 (mile post 30.5, Nugget Canyon, between Kemmerer and Cokeville, Wyoming (Gordon et al. 2001; Gordon and Anderson 2002; Pers. com. Stanley Anderson, Wyoming Cooperative Fish and Wildlife Research Unit). The FLASH system was designed by Victoria Gooch. Mid-American Manufacturing Technology Center (MAMTC) and the Wyoming Department of Transportation (WYDOT) installed the system. There were five sensors on each site of the road, and they spanned a 92-m gap in an 11,263-m long fence. The sensors were designed to detect the body heat of large animals. Once they did, flashing warning lights above a permanently visible warning sign were activated to alert drivers. The signs were placed about 300m before the crossing area. The text read "attention, deer on road when flashing." In addition, a unique geophone unit, paired with infrared scopes, was installed on the south side of the road. An additional pair of infrared scopes was installed on the north side of the road in the second year (but no geophone unit), and microwave sensors were installed south of the road. Finally, a video-camera system was installed to monitor deer moving through the crossing area. The geophone unit was designed to detect ground vibrations caused by ungulates walking through the crossing area and also served as a control for the FLASH system. The infrared scopes were part of the geophone system and had to be triggered at the same time as the geophone sensors to result in a valid detection. This was needed to eliminate false detections due to vibrations from passing trains on a nearby railroad and vehicles (Gordon et al. 2001). The microwave sensors formed a separate system, but they did not cover the entire area, and this system was susceptible to false detections as a result of passing trucks, vegetation moving in the wind and birds. Repositioning of the radar heads resulted in complete area coverage, but false detections continued, and the system was seldom used. The systems were tested and modified during the 1998-1999 season. The passive infrared sensors of the FLASH system continued to suffer from reduced sensitivity due to sun exposure throughout the 1999-2000 season and were replaced by active infrared sensors in November 2000. The FLASH system became operational on 4 December 2000 (Gordon and Anderson 2002). The FLASH system worked reliably until January 2001, after which many false detections started to occur; more than 50% of the detections were false (Gordon et al. 2001; Gordon and Anderson 2002). This was due to frost on the sensors, birds feeding on carrion in the crossing area, and snow thrown by passing snowplows. Additional problems occurred in early April 2001 as a defective transmitter started to cause false detections in response to passing trucks. However, no evidence was found that the FLASH system failed to detect deer moving through the crossing area. Nevertheless, the FLASH system was found to be too unreliable for deployment. The geophone system was never found to record false detections and seemed to be reliable (Gordon et al. 2001; Gordon and Anderson 2002; Pers. com. Matthew Johnson, Wyoming Department of Transportation). It was suggested that the geophone system could be further developed in the future. However, at one point lightning did cause malfunctioning in the geophone system.

e. Kootenay, British Columbia, Canada
In June 2002 an animal detection system was installed along Hwy 93, in Kootenay National Park in British Columbia, Canada, about 60km north of Radium, immediately north of the Dolly Varden Day-Use Area (Kinley et al. 2003; Pers. com. Nancy Newhouse Sylvan Consulting; Pers. com Hillary Page, Sage Consulting). The system was designed to detect large animals, specifically white-tailed deer (*Odocoileus virginianus*). ICBC, QWIP Technologies, OCTEC Ltd., Intranstech and FLIR Systems, Inc., all provided support for research and development. Parks Canada helped install the system. Two infrared cameras that detect heat and additional equipment were installed in the right of way. The software uses a combination of motion, speed and size to determine whether the warning system should indeed be triggered. The system, especially the cooling system of the cameras, experienced technical difficulties during the first year (June through October 2002). A modified system with different infrared cameras was installed in May 2003 (Pers. com. Hillary Page, Sage Consulting). The road length covered by the system was cut in half (from 2,000m to 1,000m) because of the different cameras. The system has standard black-on-yellow deer warning signs with amber flashing lights on top to warn drivers. The system became operational in September 2003 (Pers. com. Nancy Newhouse, Sylvan Consulting). The system is currently only active from dusk to dawn. The system may eventually be operational 24 hours a day.

f. Four Sites in Switzerland; Two Sites in Germany
In addition to the seven sites described under section a., four other animal detection systems have been

installed in Switzerland after Kistler's study was published (Kistler 2002): St. Annawald (1998), In den Böschen (1999), Grauholz (1999), Herenacher (2001) (Kistler 2002). The systems came from the same manufacturer (Calonder Energy AG), but the technology seemed to differ from the seven sites described under section a.; the new systems work on a break-the-beam principle (Kistler 2002). Some systems operate on laser beams, while other operate on infrared beams. An additional two sites have been installed in Germany between Kassel and Herleshausen in Hessen (Bundesstrasse B400, Alberberg, Eschweg) and Sachsen-Anhalt (Anonymous 2002a; Pers. com. Christa Mosler, Infodienst Wildbiologie and Oekologie, Swiss Wildlife Information Service).

g. Two Sites in The Netherlands
There were two systems installed in The Netherlands: one near 't Harde (N309) and one near Ugchelen (N304) (Pers. com. Herman van Zandbrink, Provincie Gelderland; van den Hoorn 2000). The system manufacturer was Calonder Energy AG, the same as discussed under sections a. and f. The two systems in The Netherlands were designed to detect wild boar (*Sus scrofa*), roe deer and red deer. They are solar powered and operate on a focused infrared beam that is positioned at ±50cm above the ground. The crossing areas are about 200-250m wide and have about 500-m-long fences before and after the crossing area on both sides of the road. Once an animal is detected LED warning signs with a red deer in combination with an advisory 50 km/h speed limit sign are activated. The systems are only switched on during the night. The animals tend to stay away from the road during the daylight hours (Pers. com. Herman van Zandbrink, Provincie Gelderland). The sensor boxes have to be well anchored on a concrete foundation to remain stable (Pers. com. Herman van Zandbrink, Provincie Gelderland). Ventilation of the boxes is also an issue as rain or snow may cause the lens to fog up. The distance between the sensors (200-250m) may be a little too far; smaller distances may reduce the number of false detections. Fallen trees and tall grasses can also produce false detections, as the sensors were only ±50cm above the ground. From time to time, the batteries lost too much of their power. Lightning struck one of the sensors, which caused a series of false detections. In addition, vehicles that ran off the road damaged equipment on two occasions: a sensor post and a signal pole. Another problem occurred when small birds used the sensor box as a nesting site (Pers. obs. Marcel Huijser), but mesh wire in front of the holes can solve this problem.

h. Rosvik, Sweden
In 1999 an animal detection system was installed along highway E4 near Rosvik in northern Sweden (between Piteå and Luleå) (Pers. com. Andreas Seiler, Grimsö Wildlife Research Station, Department of Conservation Biology, Swedish University of Agricultural Sciences; Kjell Ståhl, Road Administration, Luleå). The system was designed by PIK AB, Karlskrona, Sweden, and it was installed by the manufacturer and the Road Administration. The system operates on a break-the-beam principle with infrared light. The system was installed in a 100-m-wide opening in a fence, and it was designed to detect moose. When an animal is detected lights are turned on that illuminate the highway at the crossing area. This should allow drivers to see the animal better. In addition, red warning lamps in the right-of-way are activated. A standard moose crossing sign with the text "wildlife passage" is located just before the crossing area. The electricity supply was a major problem, but that issue was solved in winter 2001/2002.

i. Colville, Washington, USA
On 20 June 2000 an animal detection system was installed on Hwy 395 (mile post 290), north of Spokane, south of Colville, three miles north of Chewelah, Washington (Shipley 2001; Robinsen et al. 2002; Pers. com. J. Schafer, WSDOT Research Office; Brian Walsh, WSDOT, Traffic Safety and Operations). The system consisted of two lasers, one placed on each side of the road, two standard deer warning signs, two smaller rectangular signs that read "When Flashing," and two solar-powered red flashing beacons. The system was designed by an electrical engineer (subcontracted) and manufactured in-house at the WSDOT Research Office. The system was installed by the vendor and WSDOT. When the laser beam was broken the lights were switched on. The lasers operated on batteries with a one-week lifespan while the red strobes were solar powered. Obtaining a clear line-of-sight in the right-of-way was a problem. In addition, the sighting of the lasers proved difficult, partly because of the distance between the sensors. Sunlight heating up of the plastic boxes holding the laser equipment may have caused problems with the sighting of the laser (Shipley 2001; Robinsen et al. 2002; Pers. com. Brian Walsh, WSDOT, Traffic Safety and Operations). False detections caused the batteries to drain quicker than anticipated. Finally, the system has experienced theft of solar-power units. The system was taken down spring 2002.

j. Marshall, Minnesota, USA
Around June 2001 an animal detection system was installed along a 1,609-m-long section of Hwy 23 at Camden State Park southwest of Marshall, Minnesota (MNDOT 2001a). The system consisted of a series of laser transmitters and receivers, and was integrated by Lewis Enterprises, Inc., Saint Louis Park, MN. The vendor and MNDOT installed the system. The distance between the stations is approximately 200m (Pers. com.

Erik Lewis, Lewis Enterprises Inc.). The system had two laser beams between all stations. The lowest beam was about 65cm from the ground, and the second beam was about 30cm above the first (Pers. com. Robert Weinholzer, Minnesota Department of Transportation; MNDOT 2001b). The system was only triggered when both beams were broken at the same time. This reduced false detections as a result of, e.g., flying birds, but not as a result of heavy fog. When both laser beams in the same segment were broken amber flashing beacons were activated that continued to flash for about one minute. The warning lights were situated on standard deer warning signs. In addition, there were advisory signs that notified drivers that they were entering a test area and that deer or other animals may be present when lights are flashing. Testing was suspended during the winter months due to high maintenance costs (MNDOT 2001b). The batteries had to be replaced more often than anticipated, and the grass-herb vegetation between the sensors had to be mown regularly as the tall grass caused many false detections (Pers. com. Robert Weinholzer, Minnesota Department of Transportation; MNDOT 2001b). The Minnesota Department of Transportation plans to hardwire the system in 2004. Solar panels were considered, but maintenance, vandalism and theft were considered too much of a risk. Vegetation management in the right-of-way could be reduced if weed mats or gravel strips would be situated between the sensors (Pers. com. Erik Lewis, Lewis Enterprises Inc.).

k. Wenatchee, Washington, USA

In October 2002, an animal detection system was installed along US 97A (mile post 206), near Wenatchee, Washington. When laser beams are broken along a 213-m-long road section, yellow flashing beacons on five-by six-foot black-on-yellow warning signs with a deer profile are activated (WSDOT 2003a, b). The system was designed and integrated by Parks Griebble and Battelle Laboratories. Other signs that said “when flashing” accompanied the deer signs. When the system was triggered the lights flashed for 60 s. False detections were a problem between October 2002 and January 2003. No deer were killed between October 2002 and January 2003. The system seems to operate well (Pers. com. Jennene Ring, WSDOT North Central Region Traffic Engineer). However, deer also crossed frequently just outside of the area covered by the system. In addition, deer may loiter in the right-of-way. If these deer stay there longer than one minute, the signals are turned off, and drivers are no longer warned of their presence.

l. Yellowstone NP, Montana, USA

In October and November 2002 an animal detection system was installed along a 1,609-m-long road section of Hwy 191 (mileposts 28-29) in Yellowstone National Park south of Big Sky, Montana (WTI 2002a,b). The system was designed and integrated by Sensor Technologies and Systems, Scottsdale, Arizona. Michiana Contracting, Plymouth, Indiana, and Eagle Rock Timber, Idaho Falls, Idaho, installed the system. Each transmitter sends a uniquely coded, continuous microwave RF signal to its intended receiver (STS 2002). The transmitters and receivers are mounted about 120cm above the ground (designed to detect elk (*Cervus elaphus*)). If this signal is blocked, the receiver sends a UHF radio signal to the master station. The master station then sends the beacon-on command to the three nearest beacons. Each beacon is situated above a standard elk warning sign and signs that say, “when flashing” “next 1 mile.” The flashing beacons alert on-coming traffic that there may be a large animal on or near the road. After the designated timeout period (3 minutes), the master station transmits the beacon-off command to the beacon stations. If the signal is blocked continuously, the beacons will stop flashing after 12 minutes. The system records every break-of-the-beam, how long it lasted, date, time, and section number (there are six sections on the east side of the road and nine sections on the west side of the road). It was anticipated that these data could be accessed from a remote location through a cell phone modem. However, cell phone coverage proved to be insufficient for reliable data transmission. Each station is powered by a stand-alone solar electric power system. Each station configuration has a different power system designed to meet the load requirements of that station. The solar power systems were designed to operate without down time due to darkness and snow cover, but shady spots and snow did cause a power problem at one post. An additional battery was installed to increase storage capacity. However, it is unknown whether this is sufficient to solve the problem. The system has not been operational yet (situation September 2003) due to problems with the communication system at low temperatures. The system produced a large number of false detections, and the vendor is in the process of replacing the communication system (situation September 2003). Snow spray from snowplows also triggered the system. In addition, a car that ran off the road damaged one of the sensors, but the car is unlikely to have received major damage from the equipment. An elk sign disappeared. Furthermore, personnel from Yellowstone National Park and local residents have expressed their concern with the dimension of the posts and equipment, and the solar panels in particular. The size of equipment is thought to have a negative effect on the landscape quality, and reflection of the sun on the solar panels is a nuisance. The system is anticipated to become operational by 1 October 2003.

m. Indiana Toll Road, Indiana, USA

In April 2002 an animal detection system was installed along the Indiana Toll Road (I-80/90, around mile posts 130-140) near South Bend, Indiana (Pers. com. Sedat Gulen, Research Division, Indiana Department of Transportation). The system was designed and integrated by Sensor Technologies and Systems, Scottsdale, Arizona. Michiana Contracting, Plymouth, Indiana, installed the system. The total length covered by the system is 9,654m, but the system was split up in 6 sections of 1,609m (1 mile) each (Anonymous 2003b; Pers. com. Sedat Gulen, Research Division, Indiana Department of Transportation). A one-mile long control section follows each one-mile section with sensors. There are two blocks (each with 3 sections and their controls), which are four to five miles apart. This system is the same as described for the site in Yellowstone National Park (see section l.). The system is not operational yet due to problems with the radio system (see also section l.). The system is anticipated to become operational in the fall of 2003.

n. Sequim, Washington, USA

This system was installed along a 4,827-m-long section of Hwy 101, near Sequim, on the Olympic Peninsula, Washington. In 1999 about 10 percent of the elk herd was radio collared (Williams 1999; New York Times 2001; Carey 2002; Pers. com. Shelly Ament, Washington Department of Fish and Wildlife). An effort was made to radio collar lead cows, but this was not always possible. Receivers placed along the road scan for the frequencies of the individual radio collars 24 hours per day. When the radio-collared individuals come within about 400m of the road, the receivers that pick up the signal activate the flashing beacons that are linked to that receiver. There are four receivers in total. Typically only one receiver picks up the signal at the same time, but if the radio-collared individual is about halfway between two receivers, the signal may be picked up by both receivers. Two receivers are linked to only one flashing beacon (at both ends of the road section). The two other receivers are each linked to two flashing beacons, one for each travel direction. Standard black on yellow elk crossing signs that say "elk x-ing" accompany the flashing beacons. The system was designed and integrated by Shelly Ament and Dave Ruben, mostly with off the shelf equipment. WSDOT and the Washington Department of Fish and Wildlife installed the system. To block false detections, a device that counted the pulses of the radio signal had to be added. This device filtered out signals from other, non-elk, radio transmitters. The system became operational in fall 2000. The batteries of the radios have a three-year life span, but most of them last much longer. A second capture session took place in March 2003. There were eight elk (7 cows, 1 bull) with a radio collar in September 2003. The system seems to work well, even after a change in habitat use caused the elk to cross the road more frequently than they used too. Maintenance was limited to replacing the battery pack of a receiver and some minor repairs to a receiver. Some signs were vandalized (paint), but the signs were cleaned relatively easily afterwards.

o. Harris, Saskatchewan, Canada

In April 2002 a five-km-long section of Hwy 7 (km control section 7-04, km 0-6), near Harris, Saskatchewan, Canada, was equipped with a system that detects vehicles (Anonymous 2001; SHT 2002). Once vehicles are detected, units in the roadside are activated that alert deer through a variety of noise and light signals (IRD 2002; Pers. com. Jim Wirachowsky and Rob Bushman, International Road Dynamics). The system was designed and installed by International Road Dynamics (IRD, Saskatoon, Saskatchewan Canada). The units in the roadside are about 230m apart and consist of a small cabinet with electronics, sensors for vehicle detection, and an animal warning device (Pers. com. Bushman, International Road Dynamics). The units are powered by solar panels and batteries. When no vehicles are present the system is not active. The communication system and power supply have been improved since the system was installed (Pers. com. Rob Bushman, International Road Dynamics). In addition, MP3 players were added which allow for a great variety of sounds to be recorded and played. The system will be tested for two years. The effectiveness will be evaluated by a committee that include the vendor (IRD), SGI, Saskatchewan Highways and Transportation, Saskatchewan Environment, Saskatchewan Wildlife Federation, Royal Canadian Mounted Police, Canadian Automobile Association, Saskatoon and Area Safety Council and the West Central Municipal Government Committee (Anonymous 2002b).

Planned Systems

In addition to the animal detection and animal warning systems that have been installed (section a. through o.), we identified 20 additional locations for which an animal detection or animal warning system is planned (section p. through t., see below).

p. Thompsontown, Pennsylvania, USA

An animal detection system will be installed in October 2003 along a ±804-m-long section of Hwy 22/322 (between mile posts 360-361), just east of Thompsontown, Pennsylvania, approximately 35 miles northwest of Harrisburg (Edwards and Kelcey 2003; Pers. com. Pat Wright and Marcel Huijser, Western Transportation Institute - MSU). It is a four-lane highway with two lanes in each direction and a grass median. The system was designed and integrated by Oh Deer, Inc., Mason City, Iowa. The cost of the system is $90,000. PENNDOT and the vendor will install the system, which is designed to detect white-tailed deer in an area, as opposed to a "break-the-beam-system." The microwave detectors cover the entire right-of-way and should filter out moving vehicles, swaying branches, rain and snow. The 17 posts (each with 2 sensor units) will be placed at approximately 91-m intervals along the side of the road, and they will operate on solar power. Hardwiring was calculated at more than $50,000 whereas the cost for solar panels was estimated at $7,500 (Edwards and Kelcey 2003). Standard deer crossing signs (black on yellow) will be combined with yellow flashing lights and additional signs that say "when flashing," "next ½ M." Signs that say "animal detection test section ahead" and "end test section" will be installed before and after the sensors.

q. McDonald Creek Area, California, USA
The California Department of Transportation (CALTRANS), District 1, has identified a 965-m-long road section along Hwy 101 where elk cross the road frequently. The road section lies between mileposts 114.18 and 115.52, in Humboldt State Park, McDonald Creek area, near Eureka. This area has had a concentration of collisions, resulting in dozens of human injuries, and many dead elk (Pers. com. Susan Taylor, North Region Environmental Management Branch, California Department of Transportation). At this time there is a flashing warning light in place to alert drivers, but the flashing is continuous, independent of the presence of the elk. Since drivers tend to ignore permanent warning signs, CALTRANS is interested in installing an animal detection system. However, funding is not anticipated until summer 2004.

r. Preacher Canyon, Arizona, USA
State Route 260 from Payson to the Mogollon Rim in Arizona, northeast of Phoenix, Arizona, is being widened (Dodd et al. 2003; Pers. com. Norris Dodd and Jeff Gagnon, Arizona Game and Fish Department). This road section is known for its high number of collisions with elk. To reduce the collisions and to make the road more permeable to wildlife, a total of 17 bridges and underpasses will be built. The first section, Preacher Canyon, has been completed already. There are two wildlife underpasses located in this section near Little Green Valley. In addition, wildlife fencing (500m road length), jump-outs and one-way gates have been provided for. Although the underpasses are used intensively, many elk and white-tailed deer walk along the fence and cross the road at the end of the fence (Dodd et al. 2003). This has been demonstrated through infrared video images. In addition, the Arizona Game and Fish Department has tracked elk movements and highway crossings through GPS telemetry and assessed the wildlife-vehicle collision rate for nearly two years. This monitoring will be conducted an additional two years after fencing. Furthermore, the Arizona Game and Fish Department has proposed to install animal detection systems at two fence ends in the Preacher Canyon area, on both sides of the road. One section is 1-1.2km in road length, and the other measures about 1.5km (Pers. com. Norris Dodd, Arizona Game and Fish Department). Funding is not expected until spring 2004.

s. Pinedale, Wyoming, USA
A 3,218-m-long road section of Hwy 191, west of Pinedale, Wyoming, has a concentration of animal-vehicle collisions with pronghorn (*Antilocapra americana*) (Pers. com. Matthew Johnson, Wyoming Department of Transportation). The Wyoming Department of Transportation has proposed to install an animal detection system along this section. Funding is not anticipated until fall 2003.

t. Maine, USA
Ungulate-vehicle collisions are a major safety concern in Maine. There are two locations that are potential candidates for the installation of animal detection systems: Hwy 1 between Presque Isle and Caribou, and an 804-m-long road section on Hwy 4 near Rangeley (Pers. com. Robert van-Riper, Maine Department of Transportation). Both locations have a history of ungulate-vehicle collisions with moose as well as white-tailed deer. Funding is not anticipated until fall 2003.

u. 15 Sites, Germany
Fifteen sites are currently in the planning phase in Germany (Pers. com. Giacomo Calonder, Calonder Energy, Switzerland). No further details are available at this time.

Additional Issues
During operation and maintenance a range of problems and other issues were identified (see section a. through o.). We grouped them into four categories: false positives, false negatives, maintenance, and landscape, ecology and animals (table 3). The table shows that area-cover and break-the-beam systems seem to be particularly vulnerable to false positives and false negatives. False positives occur if the system is triggered by causes other than the presence of large animals (target species). This also emphasizes an important limitation of animal detection systems; they are only intended to detect certain large species, and they do not attempt to reduce collisions with relatively small species. False negatives occur if a large animal is present, but the system fails to detect it. Most of the causes of false positives and false negatives have already been discussed (see section a. through o.), but some have not been explicitly mentioned yet. For example, cars on driveways or side roads can also trigger area-cover detector systems and break-the-beam systems. If the driveways or side roads receive only little use, one could decide to accept a certain number of false positives. Another strategy is to accept a certain number of “gaps” in the detection system at the location of the driveways or side roads. Another problem occurs when animals pass the sensors and then loiter in the right-of-way or on the road. Most animal detection systems do not detect the animals once they have passed the sensors. This results in false negatives as the warning signs are typically switched off within a couple of minutes. Other false negatives can occur if the sensors are placed close to the road and if the animal approaches the road very quickly. If the warning signs are placed at relatively great intervals drivers may not pass a warning sign before they are confronted with a large animal. This potential problem could be addressed by installing warning signs at short intervals. Another option is to install animal detection systems at short road sections in combination with a fence that funnels the animals through the narrow crossing area.

Table 3.
Summary of the issues, problems and experiences with operation and maintenance of the animal detection and animal warning systems. √ = problem has been reported or issue applies, (√) = problem has not been reported, but it could occur. [1] = For Swedish system that illuminates the road at the crossing area and that has red warning lights in the right-of-way.

Issues, problems and experiences	Passive detector systems	Break-the-beam systems	Geo-phone system	Radio-collar system	Deer warning system
False positives					
Moving or growing vegetation					
Flying birds, nesting birds, rabbits					
Wind, rain, water, fog, snow spray (snowplows)					
Sun, heat, unstable sensors					
Insufficient ventilation in box (fog on lens)					
Frost, low temperatures					
Lightning	( )		( )	( )	( )
Long distance between transmitter and receiver					
Traffic on road			( )		
Traffic on driveways or side road	( )				
Passing trains					
Signals from other transmitters					
False negatives					
Curves, slopes not covered by sensors	( )				
Loitering animals in right-of-way not detected	( )		( )		
None of the individuals that cross have collars					
Not feasible for non-gregarious species / migrants					
Insufficient warning time	( )	( )	( )		
Some systems are only active during the night					
Maintenance					
Maintenance costs (e.g. mowing, power, fences)	( )		( )	( )	( )
Shade/snow on solar panels	( )		( )	( )	( )
Vandalism and theft of e.g. solar panels	( )		( )	( )	( )
Safety (cars of road)	( )		( )	( )	( )
Broken sensors, warning lights or other equipment			( )		( )
Period required to solve technical difficulties					
Signs (standardization, liability)					
No remote access to data (no cell phone coverage)	( )			( )	( )
Landscape, ecology, animals					
Landscape aesthetics	( )		( )	( )	( )
Animals crossing areas may change overtime	( )		( )	( )	( )
Animals may wander between fences (if present)		( )	( )	( )	( )
Small animals (non-target species) are not detected					
Animals may adapt and are no longer deterred					
Not suitable for high traffic volumes					
Continuous effort to capture animals					
Stress for the animals involved					
Not in habitat linkage zones (sound, light)		[1]			

Radio-collar systems, such as the one in Sequim (section n.), can also produce false negatives. It is unlikely that all the individuals in a certain area can be equipped with radio collars. As a consequence, the animals without a radio collar are only detected if radio-collared animals accompany them. Therefore, the system only works well for highly gregarious species. The system also works much better for a resident population than for migrants from far-away locations that may only cross the road once or twice per year.

The radio-collar system requires re-collaring effort. The batteries of the radio collars usually run out after several years, and then they must be replaced. In addition, individuals may die as a result of hunting, injuries or old age. Experts usually minimize the stress for the animals during capturing and handling, but the animals are exposed to a certain amount of stress during capturing and handling, and as a result of carrying a radio collar.

The animal warning system is special in the sense that it depends on alerting animals when a vehicle approaches. Many animal species have been shown to adapt to disturbance if this is not accompanied by an immediate and real threat. Therefore, the audio and visual signals produced by the stations in the right-of-way may not scare the animals away from the road once they have been exposed to it for a certain time. However, the animals do not necessarily have to flee away from the right-of-way to reduce the number of collisions. If the animals learn to associate the audio and visual signals with approaching vehicles, they may be less likely to enter the road at that time. If animal warning systems are effective, one should probably avoid installing them in areas that have been identified as habitat linkage zones because they promote wildlife movement, especially for dispersing individuals. These individuals may not have been exposed to the audio and visual signals before, and animal warning systems may cause a habitat linkage zone to be less effective. Additionally, these systems are not well suited for high traffic flows since the animal warnings would be running continuously in such locations.

All systems have or can have a wide variety of maintenance issues. In addition, most systems require a period during which major technical problems are identified and solved. Ironically, the presence of posts and equipment in the right-of-way may also be a problem on its own. Animal detection systems and animal warning systems may help reduce the number of animal-vehicle collisions, but they are also a potential safety hazard to vehicles that run off the road. This could lead to liability claims. Finally, as more animal detection and animal warning systems are installed, signage will have to be standardized.

Discussion and Conclusion

This overview shows that a wide variety of animal detection and animal warning systems have been installed across North America and Europe. Many of the systems encountered technical problems or experienced false positives, false negative or maintenance issues. This was to be expected since most animal detection and animal warning systems are new applications of relatively new technology. In addition, the systems are typically exposed to rain, snow, heat and frost. A few systems seem to have resolved most of the problems and operate well. Examples are the Swiss system (section a., f. and g.), the Finnish system (section b. and c.) and, although still in an experimental stage, the geophone system (section d.) and the radio-collar system (section n.). However, each system type has its own (potential) strengths and weaknesses, and one has to review them carefully before installing a system in a particular location.

It is important that animal detection systems produce very few false positives and false negatives. False positives may cause drivers to eventually ignore activated signs, and false negatives present drivers with a hazardous situation. Driver response through reduced vehicle speed or increased alertness determines how effective animal detection systems really are. Previous studies have shown that drivers do not always substantially reduce their speed in response to activated warning signs (Muurinen and Ristola 1999; Gordon and Anderson 2002). Drivers may only reduce their speed when road and weather conditions are bad or when the warning signs are accompanied with a maximum speed limit sign (Muurinen and Ristola 1999; Kistler 1998). However, failure to substantially reduce vehicle speed under all circumstances does not necessarily make animal detection systems ineffective. Minor reductions in vehicle speed are important too since a small decrease in vehicle speed is associated with a disproportionately large decrease in the risk of a fatal accident (Kloeden et al. 1997). In addition, activated warning signs are likely to make drivers more alert. Driver reaction time to an unusual and unexpected event can be reduced from 1.5s to 0.7s if drivers are warned (Green 2000). When we assume a vehicle speed of 88km/h (55 MPH), increased driver alertness can reduce the stopping distance of the vehicle by 21m (68ft). Only one study has addressed the ultimate parameter of system effectiveness. Kistler (1998) has shown that the passive infrared detection systems in Switzerland (section a.) were able to reduce the number of animal-vehicle collisions by 82 percent. This is an encouraging result, but further evaluation of different systems under different circumstances is required before we can generalize Kistler's conclusion.

We conclude that animal detection and animal warning systems have the potential to be an effective mitigation tool. However, animal detection and animal warning systems are not the perfect solution for every location. They are one tool in the transportation professional's arsenal and should be implemented only in situations where they are more desirable than other mitigation techniques. In addition, further research and development is needed before animal detection and animal warning systems can be applied on a wide scale.

Acknowledgements: This paper is part of a larger study that explores the operation and maintenance aspects of animal detection systems, their effectiveness, and their potential applications. The study is funded by the Federal Highway Administration and 15 departments of transportation: Alaska Department of Transportation and Public Facilities, and the departments of transportation of California, Indiana, Iowa, Kansas, Maryland, Montana, Nevada, New Hampshire, New York, North Dakota, Oregon, Pennsylvania, Wisconsin, and Wyoming. We would also like to thank all the people who contributed to this paper by sharing information and their experiences with the systems discussed in this paper. Finally, we thank Bethanie Walder and Edgar van der Grift for reviewing a draft of this paper.

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PREDICTIVE MODELS FOR THE LOCATION OF ANIMAL-CAR ACCIDENTS AND THEIR APPLICABILITY TO MITIGATION

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Abstract

Many provinces in Spain are suffering an increasing number of animal-car collisions in the recent years so as to become one of the main issues to the official bodies with traffic and/or environmental responsibilities. In this context, the present study has been devoted to the analysis of the causes and potential solutions to the problem in the Province of Soria (Central Spain), where more than 50 percent of the reported car accidents were related in 2000 to the presence of wild animals on the road. The study was funded by the Dirección General de Medio Natural from the Consejería de Medio Ambiente of Junta de Castilla y León (the regional body in charge of game and wildlife) with a total budget of ca. $11,650.

The modelling has been carried out at two different spatial scales, a regional one focused oo the definition of the areas with high accidentality, and a local one aimed at the search of factors determining the exact locations of accidents. The study was based on the database of car acidents provided by the Dirección General de Tráfico with indication of date, hour and location of the accident (approximated to the nearest 0.1km post), and species involved in the crash. This database comprised a total of 2,067 accident locations corresponding to the 1988-2001 period.

An initial analysis of the spatial contagion among accident locations lead to the definition a set of 41 “black sections” in roads, with 0.8 to 47.3km length each. These sectors embrace more than 70 percent of accident locations, though totalizing only a 7.7 percent of the road network of the province. A GIS-based analysis of the landscape features corresponding to these sectors was carried out in comparison with a set of 43 “white sections” interspersed among them. This task was based on the forest map of the province (1:50.000 scale) working with 1km radius circles centered on the midpoint of “black” and “white” sections. Nine land-use variables plus the length of ecotones and the diversity of substrata were used as input variables. The statistical analysis and the modelling showed the accident-prone areas to be characterized by their high forest cover, low presence of human structures, and a high diversity of vegetation types with some presence of crops.

The analysis at the accident-point scale was carried out within a total of 18 “black sections” of roads, through a sampling of 12 points with accidents recorded and 12 free of them in each section. In each point 28 quantitative and qualitative variables were measured. The variables covered the most relevant features believed to be potentially related to accidentality, such as the road characteristics from the driver’s point of view (distance to curve, signaling), habitat structure (land-uses, distance to trees), and local morphology (natural geomorphology plus human-made structures). The statistical analyses and modelling showed the accidents happening at points of animal corridors crossing the road, with vegetation, local morphology plus human structures forcing the animals to cross at predictable points.

The results thus show the potential to predict the points with higher probabilities to be accident-prone, thus opening the way for the efficient expenditure in mitigative and preventive measures for both the problem of animal-car collisions and for the alleviation of population fragmentation by roads. Moreover, modelling points to the possibility of mitigating the problem of animal-vehicle collisions in small roads by a combination of fencing and the ubication of alternative animal passes at certain points.

Biographical Sketch: Juan E. Malo and Francisco Suárez are researchers and lecturers at the Department of Ecology, Universidad Autónoma de Madrid (Spain). They work on applied zoology and environmental impact assessment with an specific research line focused on the effect of roads on vertebrates. Alberto Díez is biologist and works as freelance environmentalist in the Province of Soria. His main activity lies in the field of fauna studies for environmental impact assessment and landscape planning projects.

RESEARCH INTO WILDLIFE/VEHICLE COLLISIONS IN JASPER NATIONAL PARK

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Abstract

Wildlife collisions with vehicles and trains are examined in Jasper National Park, Alberta. The database used in this research is one of the largest and most complete wildlife/collision databases in North America. Over 4,000 wildlife collisions from 1951 to 2002 have been documented. The main species examined are elk, bighorn sheep, mule deer, moose, white-tailed deer, coyotes, wolves, black bear and grizzly bear. This level and detail of information is critical in designing mitigation solutions to reduce wildlife collisions.

There are a variety of variables that influence collision rates ranging from age class, sex, type of wildlife, vehicle volumes, vehicle type, season, time of day and transportation category. From 1980 to 1999, collisions with wildlife averaged 149 large animals per year. For some species these collision rates are both statistically and biologically significant. In addition, collisions on highways and the railway affect both local and regional wildlife populations. Using collision data as indicators of wildlife composition adjacent to transportation corridors shows changes have occurred in the wildlife composition adjacent to transportation corridors.

Additional research includes an updated assessment of the effect of reduced speed zones in reducing wildlife collisions and an assessment of Strieter Lite Reflectors. Reduced speed zones reduced the rate of collisions with elk and other wildlife but had a negligible affect on reducing bighorn sheep collisions. An analysis of Strieter Lite Reflectors is in preparation. A description of mitigation measures that have been used in Jasper National Park is also provided including suggestions on improved mitigation.

RESULTS OF RECENT DEER-VEHICLE CRASH INFORMATION CLEARINGHOUSE ACTIVITIES

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Abstract: Deer-vehicle crashes (DVCs) are a significant problem in many areas of the United States. Approximately two years ago the Wisconsin Department of Transportation (WisDOT) funded a regional deer-vehicle crash information clearinghouse (DVCIC). Representatives from the DOT and the Department of Natural Resources (DNR) of five states in the Upper Midwest (i.e., Michigan, Minnesota, Illinois, Iowa, and Wisconsin) are involved with the clearinghouse project.

During the last two years, clearinghouse staff have worked on several tasks related to DVCs. This paper briefly summarizes the current status of the key results from these ongoing tasks. First, a DVC countermeasure toolbox document is nearing completion. The primary objective of the toolbox is to provide a resource with enough detail that can assist professionals with their decisions related to the mitigation of DVCs. Published research, if available, for a number of DVC countermeasures is summarized in the toolbox document. Draft versions of five countermeasure summaries (two ongoing) are described here and the remainder are located on the clearinghouse webpage: www.deercrash.com. Second, DNR and DOT representatives from the region were interviewed about their collection and estimation methods related to vehicle travel, reported DVCs, and deer population data. The objective of this survey was to determine and define the similarities and differences of these databases. The results will impact the usefulness of any regional data summaries that are completed. A short summary of some key preliminary results from that survey is included. Third, two graduate students that worked for the clearinghouse recently completed their master's degree theses. The results of their work are currently being finalized and summarized, and their general conclusions are briefly summarized in this paper. The subject areas of their work included the development of prediction model(s) for DVCs in Wisconsin counties, and the analysis of DVC patterns in the vicinity of existing deer crossing signs. The latter project also included some suggested guidance for the placement of deer crossing signs. Other ongoing tasks of the clearinghouse staff include the development of a document summarizing gaps in DVC countermeasure research and some suggested criteria or standards for DVC crash reduction research. The creation of a deer, vehicle, and DVC data summary for the five-state region is also ongoing.

The objective of the DVC information clearinghouse and its activities is to provide information about DVCs that help better describe the problem. The DVCIC also assists professionals in their DVC mitigation decisions.

Introduction

It has been estimated that over 1.5 million deer-vehicle crashes (DVCs) occur each year in the United States, but less than half of them are reported (1). In Wisconsin, approximately one in seven reported crashes are DVCs. A summary of the reported DVC and/or animal-vehicle crashes for the Upper Midwest region is show in table 1.

In July 2001, the Wisconsin Department of Transportation (WisDOT) initiated a regional DVC Information Clearinghouse (DVCIC). Five states in the Upper Midwest (i.e., Michigan, Minnesota, Illinois, Iowa, and Wisconsin) are involved with this project. During the last two years the clearinghouse staff have been involved with three projects. First, the DVCIC staff have combed through hundreds of documents that summarize the current state of the knowledge related to DVC countermeasure effectiveness. The result of these activities has been the ongoing creation of a DVC Countermeasures Toolbox. The activity is ongoing and should be finalized this year. Second, a regional database management telephone survey has been completed, and the preliminary results are available. This survey asked DNR and DOT representatives about their collection and estimation methods of data related to DVCs (e.g., crash reports, carcass pick-up, deer population estimates, etc.). Third, two graduate students recently finished their master's theses. The subjects of this work included DVC patterns in the vicinity of existing deer crossing warning signs, and the development of county DVC prediction models. Some of the key results from all three of these activities will be briefly summarized here. More detailed discussions are either already available at www.deercrash.com in draft form, or this information will be published (or on the webpage) soon. The future activities of the DVCIC are presented at the end of this paper.

THE DVC Countermeasure Toolbox

The development of a DVC countermeasures toolbox is an ongoing task. The objective of the toolbox is to provide information to decision-makers about the current state of the knowledge related to the effectiveness of DVC reduction measures. The focus of the toolbox is to summarize documented and peer-reviewed published research, if available, about the relationship between 16 DVC countermeasures and what we know about their direct DVC impact. The current state-of-the-knowledge about the characteristics of each measure is identified, if relevant, and the countermeasure objectives described. The validity and transferability of the DVC countermeasure research is also investigated. However, documentation about the "effectiveness" of the DVC countermeasures also ranges from the anecdotal to some peer-reviewed research journal publications. DVC countermeasure studies that are poorly documented, questionably designed, and/or invalid or unrepeatable in their statistical validity are common. This situation is most likely the result of the variability, diversity, and complexity of the problem.

Table 1.
Upper Midwest Deer-Vehicle Crashes – Year 2000/01

State	Pre-Hunt Numbers in Deer Herd	Deer-Vehicle Crashes	Deaths	Injuries	Vehicle Damage**
Michigan	1,800,000	67,000	11	2,100	$114 mil
Wisconsin	1,500,000	19,900	9	800	$34 mil
Minnesota*	960,000	19,000	2	450	$32 mil
Illinois	750,000 (est.)	22,900	5	920	$39 mil
Iowa*	210,000	7,800	3	600	$13 mil
Total	5,220,000	136,600	30	4,870	$232 mil

**2000 Reported deer-vehicle or animal-vehicle crashes.*

***Damage estimate assumes $1,700 property damage per reported crash.*

The toolbox will attempt to summarize the current state of the knowledge about the DVC-reduction capabilities of the 16 countermeasures listed below. Those countermeasures in the list that are in italics are currently being summarized. The remainder of the summaries is in draft form. The objective is to have the entire toolbox finalized very soon. The reader is referred to the webpage (www.deercrash.com) for these draft summaries, and a complete listing of the references used.

- Noise/sound/whistle devices
- Roadside reflectors/mirrors
- Deer crossing signs
- Intercept feeding
- Speed limit reduction
- Highway lighting
- Repellents
- Deer flagging models
- Deicing salt alternatives
- In-vehicle technologies
- Wildlife grade separations and crossings
- Vegetation/roadside management
- Hunting or herd management
- Fences/barriers
- Highway planning
- Public education/awareness

The following paragraphs describe some of the toolbox findings related to five of the countermeasures listed. These five countermeasures include roadside reflectors/mirrors (draft form), deer crossing signs (draft form), speed limit reduction (draft form), fencing/barriers (ongoing), and wildlife grade separations and crossings (ongoing). The summaries for the first three countermeasures have been completed and are in draft form (see www.deercrash.com), but the last two are currently ongoing and only general findings are currently documented. A complete list of the references used in each summary is also at that web address.

Roadside Reflectors/Mirrors

The roadside reflector/mirror studies and literature reviewed for the toolbox were segmented into four categories. Past reflector/mirror research typically used a cover/uncover, before-and-after, or a control/treatment study approach to evaluate their impact. Researchers have also either observed deer movements as they evaluated the impact of roadside reflectors/mirrors on deer roadkill and/or DVCs or specifically considered deer behavior toward reflected light. Many of the studies summarized (which represent a sample of the many documents available), whether they focused on deer roadkill and DVC impacts or deer behavior, had conflicting results. Overall, five of the 10 studies summarized for the toolbox had conclusions that indicated roadside reflectors did not appear to impact deer roadkill or DVCs, and two of the 10 concluded that they did. Three of the 10 studies summarized appeared to reach inconclusive or mixed results. Most of the studies that evaluated deer behavior (many dealing with captive deer) were also inconclusive or concluded that the deer either did not appear to react to the light from the reflectors and/or quickly became habituated to the light. The experimental designs and details of all the studies evaluated did vary. The large amount of speculative and anecdotal information about roadside reflector/mirror DVC-reduction effectiveness is not included in the summary.

At this point in time it is difficult to conclude the roadkill- or DVC-reduction effectiveness of roadside reflector/mirror devices due to the conflicting results of the studies summarized. It is recommended that the completion of a definitive roadside reflector/mirror DVC-reduction effectiveness study be considered. A well-designed widespread, long-term statistically valid study of comparable and well-defined maintained roadside reflector treatment and control roadway segments (with consideration given to local deer travel patterns) is suggested.

Deer Crossing Signs

Two studies were summarized that implied there were speed reduction impacts related to the lighted deer crossing sign design improvements they were evaluating. However, the outcome of a more in-depth study by some of the same researchers of lighted and animated deer crossing signs did not appear to indicate that the resultant vehicle speed reduction resulted in a reduction of the number of deer roadkill. Unfortunately, these study results are based on only 15 weeks of data, and the variability in DVCs and the factors that impact their occurrence also limit their validity and transferability. It is proposed that additional and more long-term research be completed to support or refute the speed- and DVC-reduction impacts of existing and proposed improvements to deer crossing warning signs. The attention value of typical deer crossing signs is currently the focus of a study in Minnesota.

A number of systems that combine dynamic signs and sensors are also being considered or have been installed (e.g., Montana, Indiana, Minnesota, and Wyoming). Several of these systems are briefly described in draft toolbox at www.deercrash.com. The recent development of these systems requires an initial evaluation of their activation reliability. One key to the successful application of these systems is the minimization of false activations. The operation and effectiveness of some of the systems described in the draft toolbox are currently being studied, but only the Nugget Canyon, Wyoming system analysis appears to have been documented at this time. The researchers doing the evaluation concluded that when the system worked properly it produced a small, but statistically significant, reduction in average vehicle speeds. However, they did not believe the observed average vehicle speed reduction would reduce DVCs. Reductions in average vehicle speeds were also found when the lights on the signs were continuously flashed and/or a deer decoy was introduced on the roadside. In fact, the largest average vehicle speed reduction calculated was when the lights were flashing and the deer decoy was present. Another benefit of these types of systems is that the drivers become more attentive to the roadside, and this may lead to reductions in DVCs without an apparent reduction in average speed. At least one paper in this compendium also summarizes several European studies that did show some vehicle reduction, and may be included in the final draft of the toolbox.

Speed Limit Reduction

Two studies that evaluated speed limit reduction as a potential DVC countermeasure were reviewed for the toolbox. In both cases the researchers suggested that there was a relationship between animal-vehicle collisions and posted speed limits. In certain instances, but not all, their research results appear to show a less-than-expected number of animal-vehicle collisions along roadway segments with lower posted speed limits. To reach this conclusion, one study statistically compared the proportion of roadway mileage with a particular posted speed limit to the proportion of animals killed along those segments. The other study compared the frequency and rate per roadway length of animal-vehicle collisions before and after a posted speed limit change. No studies were found that focused on the number of white-tailed DVCs and posted speed limit.

There are several limitations to the posted speed limit reduction research that has been completed. Overall, like the analysis of many other animal-vehicle crash countermeasures, the two studies summarized do not address (or document), and/or attempt to control for, a number of factors that could impact the validity and usefulness of their conclusions. For example, neither study quantitatively considered the increase in traffic volume or adjacent animal population variability along the segments considered. A comparison of the proportion of animal-vehicle collisions to a proportion of particular roadway mileage also assumes a uniform distribution of animal population, and tends to ignore any positive or negative correlations that might exist between roadway design, topography, posted speed limit, operating speed, and animal habitat. Effectively determining and defining a relationship (if any) between reduced posted speed limits (or operating speeds) and the number of animal-vehicle collisions along a roadway segment will require additional research studies that attempt to address, control for, and/or quantify the impact and potential interaction of these and other factors.

One of the studies summarized also concluded that the choice of vehicle operating speed appeared to be primarily impacted by roadway and roadside design features (versus posted speed limit). This is a conclusion that is generally accepted in the transportation profession, and primarily supports the fact that a reduction in posted speed limit that is not considered reasonable by the driving public will generally be ignored (without significant enforcement presence). This type of situation has been shown to increase the general possibility of a crash (not DVCs) between two vehicles along a roadway because some drivers will slow and others will not.

Ongoing Reviews – Fencing/Barriers and Wildlife Grade Separations and Crossings
A preliminary scan of several documents related to wildlife grade separations/crossings and fencing/barriers has been completed. The final draft summary of these documents, along with findings and conclusions, will be released soon. The preliminary document scan reveals that these two measures have been widely implemented, and appear to have been studied to a greater extent than some of the other countermeasures in the toolbox. In addition, these two countermeasures are also commonly and appropriately implemented together. For this reason, determining the DVC-reduction effectiveness of one or the other may be difficult.

The effectiveness of wildlife separations/crossings is often measured by whether or not the device is used by the animals for which it is built. Not all of the animals that use a wildlife crossing, however, would result in a DVC. The change in DVCs that results from the implementation of a crossing is of interest. Some of the key decisions that need to be made with respect to wildlife grade separations and crossings include the location, height, width, and length of the measure. These characteristics also have an impact on the DVC reduction and/or use of a wildlife grade separation or crossing. There have been some general design suggestions or rules for some of these characteristics.

Studies that focus on the effectiveness of different deer fencing heights have also been documented. It appears, however, that these studies have had some inclusive or conflicting results. The key decision and considerations related to fencing include its location, height, length, and necessary maintenance. In some cases, the studies that have been completed have apparently produced inclusive study results because of researcher decisions related to these characteristics. For example, the study of fencing that is not maintained during the research project time period may invalidate the data collected. How fencing impacts animal migration and relates to the surrounding topography and roadway grade separations are also important to its effectiveness. Several studies of fencing effectiveness at removing animals from an area have also focused on the protection of valuable crops. The transferability of these types of results to the roadside needs to be investigated. In general, a fencing height of 8 to 10 feet is often suggested, but documentation about what percentage of white-tailed deer may be removed from a right-of-way (or the DVC-reduction effectiveness) due to different fencing heights may not exist.

Ongoing Data Management Survey

DNR and DOT representatives from the five states involved with the DVCIC were interviewed about their collection and estimation methods related to vehicle travel, reported DVCs, and deer carcass and population data. It is important to know this information in order to define the extent of the DVC problem in the region. Secondary questions about DVC-related activities, countermeasure implementation, DNR/DOT interaction, and crossing sign locations were also asked. Overall, 27 questions were submitted and the answers are currently being summarized. The general objective of the survey was to determine and define the similarities, differences, and usefulness of the existing databases. The methods used to collect and estimate these data will be shared, and a knowledge of how the data are defined will allow them to be more properly compared and combined both within and between different states, and from year to year. The combination or comparison of data from different systems that may not define the data in a similar manner can be invalid or will require additional explanation.

Some preliminary results from survey include the following. Annual deer populations are estimated in each of the five states, and they are either pre- or post-hunt. Some of these estimates are done by county, and others are done by deer management unit. The procedure used by Wisconsin to do its estimate is very well documented. It appears that DNR personnel are rarely consulted about animal-vehicle conflicts during the planning of roadways, or during the selection of locations for deer crossing signs. Wisconsin appears to be the only state in the region that contracts and records the number of deer carcass collections in each of its counties. In the other four states, carcass collection is primarily a state or local DOT activity, and the number and location of the carcasses collected are not typically recorded. DNR involvement with DVCs is often regulated to salvage tag or permit administration. The reported number of DVCs in a state can sometimes include both officer- and self-reported incidents. Finally, the minimum crash-reporting threshold for the five states varies from $400 to $1,000, and most states have changed this threshold in the last 10 years. The daily vehicle volume along each roadway is estimated every one to three years in each state.

Recently Completed and Ongoing Research Work

In May 2003 two University of Wisconsin graduate students completed their master's thesis work. These projects included an analysis of DVC patterns near existing deer crossing signs, and the development of Wisconsin county DVC prediction models. A summary of the approach used in the first study is presented below. A paper that describes the results of this study is currently being considered for publication. The results from the second project are being updated and finalized. Only some preliminary conclusions are presented here.

The DVC patterns near typical deer crossing signs have never been systematically considered. However, a typical assumption by drivers is that these signs represent roadway segments that have higher than the typical number of DVCs and/or deer crossings. The official guidance for the installation of deer crossing signs is mostly qualitative, and indicates they should be installed where animal crossings are unexpected. Past studies of deer crossing signs have generally focused on their enhancement and assumed that they are correctly located, but ineffective at DVC reduction. The proper installation of these signs at locations with a DVC problem would be more consistent, use limited resources more efficiently, and maximize whatever potential impact these signs might have on drivers. A research project completed by DVCIC staff investigated DVC patterns near 38 pairs of deer crossing sign pairs in five Wisconsin counties. Three years of reported DVCs were collected and summarized for the roadway segments between and within two miles of these pairs. Overall, one-quarter-mile and average segment DVC frequencies and rates were calculated between and outside each sign pair, and compared with each other and the county and state averages. Overall, the DVCs per mile and DVC rate (per volume) between the signs were found to be statistically greater than these measures outside the signs. Fourteen of the 38 sign pairs were also further evaluated because their average and peak DVC measures were all located between the signs. The findings of this research were used to develop a general set of installation guidelines for deer crossing signs.

The ability to estimate the number of DVCs expected to occur within a jurisdiction could be used to alter those activities or physical characteristics that may result in a DVC reduction. At least two or three county-level DVC models have been developed in the past. The dependent variable for these models has often been DVC density in crashes per square mile. Typical measures used in roadway safety research include frequency in crashes per year and rate in crashes per a measure of vehicle travel. A research project completed by DVCIC staff attempted to develop three Wisconsin county DVC models. The dependent variables for these three models were crash density, frequency, and rate. First, 12 of the 72 counties in Wisconsin were removed from consideration due to a lack of data or concerns about its validity. The relationships between and among variables related to deer and human populations, vehicle travel, roadway mileage, land use types and acreages (e.g., woodland, farmland, etc.), snow depth, and several other county characteristics were also evaluated. Several combinations and transformations of these variables were also investigated. Variables related to the level of deer and vehicle travel in a county were included in at least two of the three models. The DVC prediction model with the best fit used DVC frequency (i.e., DVCs per year) as its dependent variable. The results of this study are currently being finalized for potential submission and publication.

Future DVCIC Activities

The objective of the DVC information clearinghouse and its activities is to provide useful information about DVCs and some potential countermeasures to professionals and the general public. The long-term goal of the DVCIC is to help decrease the number of DVCs in the United States. The countermeasure toolbox, database management survey, and research activities described in this paper are the ongoing first steps towards the DVCIC objective and goal. In the near future, DVCIC staff will be finalizing, distributing, and transferring the content of the DVC countermeasures toolbox, the database management survey results, and the research results. Other ongoing tasks at the clearinghouse include the development of a document that summarizes the gaps in DVC countermeasure research and also suggests some criteria and/or standards for DVC crash reduction research. The creation of a deer, vehicle, and DVC data summary for the five state region will also be a product of the DVCIC.

Disclaimer: The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not reflect those of the Wisconsin Department of Transportation or the Federal Highway Administration.

Biographical Sketch: Dr. Knapp is an assistant professor/program director in the Engineering Professional Development Department and the Civil and Environmental Engineering Department at the UW-Madison. He is also the director of the Upper Midwest Deer-Vehicle Crash Information Clearinghouse. He has over 12 years of experience in the areas of transportation consulting and research. The majority of his experience is in the analysis of traffic operations and safety, roadway design, and traffic control. His primary areas of research are the safety and mobility impacts of roadway system characteristics. Immediately prior to joining the University of Wisconsin, Dr. Knapp was an assistant professor at Iowa State University, and manager of Traffic and Safety Programs at the Center for Transportation Research and Education. He is currently a licensed professional engineer in Illinois, Michigan, and Iowa.

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THE WILDLIFE PROTECTION SYSTEM: EARLY SUCCESSES AND CHALLENGES USING INFRARED TECHNOLOGY TO DETECT DEER, WARN DRIVERS, AND MONITOR DEER BEHAVIOR

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Problem Statement

Wildlife-vehicle accidents result in substantial personal, environmental and economic losses, including human injuries, fatalities, loss of wildlife, and vehicle damage. In British Columbia, about 16,000 such collisions occur annually, including unreported cases. This typically results in two to three human deaths (Sielecki 2001) and claims to the Insurance Corporation of British Columbia (ICBC) of over CDN$25 million, excluding "swerved-to-miss" accidents. As Farrell (2002) notes, the problems associated with wildlife-vehicle collisions are global, pervasive and increasing, yet most of the literature suggests that many mitigation techniques have limited utility because they are ineffective at reducing collisions or have large impacts on natural wildlife movements.

Project Objectives

The *Wildlife Protection System* (WPS) is designed to use infrared cameras to detect wildlife on or near highways. When wildlife is detected, flashing lights are triggered, warning drivers to reduce speed and anticipate wildlife on the roadway. The objectives of this project are to:

1. Determine the ability of the WPS to detect wildlife and warn motorists.
2. Determine the speed response of drivers to wildlife-activated warning lights.
3. Document wildlife behavior near highways using 24-hour infrared video footage in order to develop more effective wildlife collision mitigation strategies.

Funding Source and Total Budget

Funding for this project was provided by the Insurance Corporation of British Columbia, Intrans Tech (part of the Rainbow Group of Companies), Parks Canada, the BC Conservation Foundation, the Columbia Basin Fish and Wildlife Compensation Program, FLIR Systems, Inc., OCTEC Ltd., and QWIP Technologies. In 2002, over CDN$600,000 was spent on development and preliminary testing of the system.

Methodology

The first trial was initiated in the summer of 2002 in Kootenay National Park, British Columbia, Canada. In the trial, a camera was mounted on a 6-m pole at each end of a 2-km stretch of highway. Adjacent to each pole was a trailer containing a computer (with tracking software), two radar guns, and a conventional digital video camera. Continuous (24-hour) infrared and conventional video footage was recorded. In addition, an "event log" was generated in an Excel spreadsheet that recorded traffic speeds before and within the test zone, and animal detections within the zone. A number of technical difficulties prevented the system from becoming fully operational in 2002. However, we were able to view 24-hour infrared video footage of deer behavior in the highway right-of-way (ROW) over 16 days from 29 August to 7 October 2002.

We recorded the number of deer present on the ROW during five-minute samples at the beginning of every half-hour, along with their location and some behaviors (in ditch, on roadside approaching highway, on roadside retreating from highway, standing on road, crossing road), whether they were running, whether a car was present, and if crossing, whether the attempt was successful and whether there was a near-miss with a vehicle.

Summary of Findings and Their Applications

Successes from this preliminary trial include confirmation of the camera's ability to track wildlife within a 1-km range, and collection of infrared video data, providing a unique opportunity to study wildlife behavior on and near road systems.

We recorded 1131 deer-minutes of behavior (number of deer events multiplied by the time they were present in the sampling period). Based on hourly totals of deer-minutes, we stratified the 24-hour period into night (midnight to 7 AM), midday (7 AM to 7 PM) and evening (7 PM to midnight). Both the number of deer and the duration of their stay in the ROW were greatest during the night, intermediate during the evening, and lowest during midday, so the number of deer-minutes per hour was over 2x higher at night than evening, and over 15x higher at night than midday. However, deer were more likely to exhibit behaviors of concern to motorists during midday. For example, within sample periods, the following measures were higher per deer during midday than evening or night, respectively: approaches to highway (0.70, 0.60, 0.43), running approaches to highway (0.42, 0.09, 0.03), stepping onto the highway surface (0.14, 0.10, 0.10), attempted or successful highway crossings (0.12. 0.08, 0.08), and crossing in front of oncoming cars (0.05, 0.00, 0.02). The relatively higher rate of high-risk behaviors during midday is compounded by the fact that vehicle numbers were much higher during midday (263/hr) than evening (182/hr) or night (70/hr). Driving in daylight probably increases deer visibility dramatically, but being within the line-ups of cars more typical of midday presumably decreases the driver's field of view and may increase the collision hazard and severity associated with a driver swerving or making a sudden stop.

Implications for Future Research/Policy

If further test trials are successful, this new technology should be used to reduce wildlife-vehicle collisions. The WPS offers several advantages over conventional mitigation strategies including:

- Wildlife cannot become habituated as they might to scents, reflectors, and other deterrents because the system focuses on the actions of motorists, rather than animal behavior.
- Drivers are less likely to become complacent to the warning system because it is only triggered temporarily when wildlife is present.
- This system does not interfere with the natural movement of wildlife, nor require the construction of overpasses or underpasses to allow for highway crossings.
- In contrast to permanent structures, such as overpasses and underpasses, this system is highly portable and can be moved seasonally to high risk areas, or relocated in response to changing wildlife populations and movements, adjacent land-use and traffic patterns.
- This system can operate 24-hours/day, in contrast to some mitigation tools that operate only at night. Wildlife behavior data collected from this trial in August to October, 2002 suggests that despite the number and duration of deer events in the ROW being higher at night or evening than midday, deer exhibit behaviors more likely to result in accidents during midday. High midday traffic volumes may partly negate the visibility benefits that would otherwise exist from driving in daylight.

The portable infrared video recording system could also be used as a research tool for wildlife accident mitigation such as documenting wildlife crossing rates prior to construction of new highways to determine best locations for overpasses and tunnels (if they are deemed necessary) and assessing the effectiveness of other existing mitigation tools, such as reflectors, repellents, and whistles by documenting wildlife behavioral response. The system could be employed in a broad range of other off-highway wildlife behavior research as the trailers are fully portable, unobtrusive, and provide 24-hour/day recordings.

The 2003 tests will focus on continued assessment and refinement of the technical aspects of the WPS, evaluating the effectiveness of the warning lights in altering driver speed, and documentation of wildlife behavior in the test zone.

Website for More Info: For more information on this project, check the BC Conservation Foundation website at http://bccf.com/wvap/ or Intrans Tech's website at http://www.intranstech.com/.

Biographical Sketch: Nancy Newhouse is a senior biologist with Sylvan Consulting Ltd. She is currently under contract to the Insurance Corporation of British Columbia (ICBC) to assess a number of wildlife accident mitigation strategies, including the Wildlife Protection System (WPS). Funding for the WPS has been provided by a coalition of partners including ICBC, Innovative Transportation Technology Inc. (Rainbow Group of Companies), Parks Canada and the Columbia Basin Fish and Wildlife Compensation Program. Nancy has also been actively involved in numerous other wildlife conservation projects including badger research, riparian research and wildlife viewing programs. Nancy holds a Bachelor of Science and a Master of Environmental Design degree.

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