

**Methods to Reduce Traffic Crashes Involving  
Deer: What Works and What Does Not**

James H. Hedlund\*  
Paul D. Curtis\*\*  
Gwen Curtis\*\*  
Allan F. Williams

October 2003

*\*Highway Safety North, Ithaca, NY*  
*\*\*Cornell University, Ithaca, NY*

---

**INSURANCE INSTITUTE  
FOR HIGHWAY SAFETY**

1005 NORTH GLEBE ROAD ARLINGTON, VA 22201  
PHONE 703/247-1500 FAX 703/247-1678  
<http://www.highwaysafety.org>

## **ABSTRACT**

More than 1.5 million traffic crashes involving deer are estimated to occur each year in the United States. These crashes produce at least \$1.1 billion in vehicle damage and about 150 fatalities annually. Deer-related crashes are increasing as both deer populations and vehicular travel increase. Many methods have been used in attempts to reduce deer crashes, often with little scientific foundation and limited evaluation. This paper summarizes the methods and reviews the evidence of their effectiveness and the situations in which each may be useful. The only widely accepted method with solid evidence of effectiveness is well-designed and maintained fencing, combined with underpasses or overpasses as appropriate. Herd reduction is controversial but can be effective. Deer whistles appear useless. Roadside reflectors appear to have little long-term effect, although additional well-designed evaluations are needed before firm conclusions can be drawn. Both temporary passive signs and active signs appear promising in specific situations, but considerable research is required to evaluate long-term driver response and to improve and test deer detection technology for active signs. Other methods using advanced technology require substantial additional research and evaluation.

## **INTRODUCTION**

Deer and motor vehicles do not share the nation's highways gracefully or safely. Although precise data are not available, the best estimates suggest that more than 1.5 million deer-vehicle crashes (DVCs) in the United States in 2002 produced at least \$1.1 billion in vehicle damage, about 150 human fatalities, and at least 1.5 million dead deer (Conover et al., 1995; DeerCrash, 2003; Williams, 2003a). These numbers are rising every year as both the number of deer and the amount of motor vehicle travel continue to increase.

Many methods have been proposed and implemented in attempts to reduce DVCs. Few have been documented or evaluated well. This summary reviews the methods and evidence of their effectiveness. For the methods with solid evidence we discuss conditions most appropriate for their use. For promising methods we suggest additional research. Finally, we provide data collection and reporting recommendations that, if implemented, will help to understand the DVC problem more clearly and evaluate DVC control methods more accurately.

### **Deer Population and Crash Trends**

Deer inhabit all of the United States, including Hawaii, where they have escaped from captivity. White-tailed deer are common east of the Rocky Mountains, especially in northeastern, southeastern, and midwestern states; mule deer are found from the Rocky Mountains west, with smaller populations of black-tailed deer in some locations. In southern areas, white-tailed deer usually occupy fixed range areas year-round. In northern areas with deep snow, white-tailed deer may travel many miles between summer

ranges and winter deer yards. These movements depend somewhat on winter severity and spring green-up. Mule deer have regular migratory routes between summer and winter ranges.

Deer population totals are difficult to estimate, but there is abundant evidence that deer populations have increased over the past century. McCabe and McCabe (1997) estimated a North American white-tailed population of 24-33 million in 1500, before European settlement began, which dropped below 2 million by 1900 and then rose to 16-17 million by 1997. Other estimates placed the total U.S. deer population at 25-30 million by the end of the twentieth century; for example, Knapp (2001) estimated more than 27 million deer. Knox (1997) estimated that Virginia's deer population increased from about 25,000 in 1923 to about 900,000 in 1994.

Nationwide DVC counts also are difficult to estimate, but there is strong evidence that they are increasing. Most state crash data files record crashes with animals but do not distinguish deer from other animals such as moose, elk, horses, and cattle. The National Highway Traffic Safety Administration (NHTSA) Fatality Analysis Reporting System, a census of all fatal traffic crashes, shows an average of 154 fatal crashes involving animals in the four years 1998-2001, compared with an average of 111 in the four years 1992-95, an increase of 39 percent. NHTSA's General Estimates System estimates about 274,000 total police-reported crashes with animals annually in 2000-01 compared with 222,000 in 1992-93, an increase of 24 percent (Williams, 2003a). Data from states that distinguish deer from other animals suggest that most animal crashes involve deer: 99.7 percent in Michigan (Highway Safety Information System (HSIS), 1995), more than 90 percent in Minnesota (HSIS, 1995), and 93 percent in Pennsylvania (Williams, 2003a).

DVCs increased by 54 percent in Pennsylvania from 1994 to 2000 (Williams, 2003a), by 51 percent in Iowa from 1990 to 1997 (Hubbard et al., 2000), and by 69 percent in five states combined (Illinois, Maine, Michigan, Minnesota, and Utah) from 1985 to 1991 (HSIS, 1995). In 1999, 16 percent of all reported traffic crashes in Wisconsin were DVCs, up from 5 percent in 1978 (DVCR Working Group, 2000). The number of DVC claims at a major automobile insurance company rose 21 percent from 1998 to 2001 (Williams, 2003b).

Many DVCs are not reported to police. In a small telephone survey in New York, Decker et al. (1990) found that police were notified of about half, and insurance companies of less than half, of the DVCs. Taking the police underreporting into account, Conover et al. (1995) estimated that about 1.5 million DVCs occurred annually in the mid-1990s. The reported crashes alone produced more than \$1.1 billion in vehicle damage (in 1993 dollars); the unreported crashes added additional vehicle damage costs. More recently, an estimated 131,500 DVCs occurred in 2000 in the five upper midwest states of Illinois, Iowa, Michigan, Minnesota, and Wisconsin, producing 23 deaths, 4,650 injuries, and \$222 million in vehicle damage (DeerCrash, 2003).

DVCs are seasonal. White-tailed deer DVCs peak in October and November during the breeding season, with a secondary peak in May and June as yearling deer disperse from their birth ranges (Allen and McCullough, 1976 (Michigan data); Decker et al., 1990 (New York data); Puglisi et al., 1974 (Pennsylvania data); HSIS, 1995 (data for five states combined)). Mule deer DVCs are most frequent during the spring and fall migrations (Messmer et al., 2000). DVCs occur predominantly in darkness, on high-speed, two-lane, rural roads (HSIS, 1995; Williams, 2003a), especially when forest cover is close to the roadway (Finder et al., 1999).

## **Study Approach**

We reviewed both published studies and other information obtained from highway safety, motor vehicle insurance, and natural resources sources. Three review studies were especially useful: Danielson and Hubbard (1998), DeerCrash (2003), and Putman (1997). The DeerCrash website ([deercrash.com](http://deercrash.com)) contains an extensive bibliography and periodically updates summaries of information on specific methods. Studies involving animals other than deer were not reviewed systematically but were included when appropriate.

Three general strategies to reduce DVCs are to modify driver behavior, modify deer behavior, or reduce the number of deer. Each can be attempted in several ways. We summarize the theoretical basis and supporting evidence for each method and assess the available evaluation studies. We did not conduct a formal meta-analysis with specific criteria to define high-quality studies. Rather, we give more weight to methods with evidence from studies with sound designs, controls for potentially confounding influences, adequate sample sizes, and consideration of how the method's effectiveness may change over time.

## **METHODS TO AFFECT DRIVER BEHAVIOR**

Three methods to affect driver behavior are to increase driver awareness of deer and the possibility of DVCs, improve the visibility of deer on or approaching roadways, and reduce driving speeds so drivers have more time to avoid crashes.

### **General Education**

General education consists of efforts to provide information about DVC dangers so drivers will watch more carefully for deer and drive more slowly. Typical methods include news stories and public awareness campaigns in peak DVC seasons. About half the states use some form of general education (Romin and Bissonette, 1993; Sullivan and Messmer, 2003).

None of the general education campaigns has been evaluated. In other traffic safety areas such as impaired driving and occupant protection, stand-alone general education campaigns have not been effective in modifying driver behavior (O'Neill, 2001; Williams, 1994). Campaigns can be effective

when they present new information that directly affects drivers and that is reinforced by something drivers can observe. For example, publicity announcing increased enforcement of a safety belt use law can be effective when the publicity is followed with extensive law enforcement presence. It is unlikely that DVC general education is useful unless it provides information on very specific and time-sensitive situations, such as the beginning of mule deer migration across a short road segment. In these situations, either temporary passive or active signs may be more effective than general campaigns.

## Signs

Roadside signs attempt to warn drivers of specific locations and even times when deer may be present. Passive signs have a fixed message at all times, though they may use lights or animation to attract attention. Active signs are lighted when deer are detected on or near the roadway.

**Passive signs:** Roadway signs warning drivers of deer-crossing locations are used in almost all states (Romin and Bissonette, 1993; Sullivan and Messmer, 2003). Most are passive: fixed signs in fixed locations, with the same message in words or pictures at all times and in all seasons, usually a standard yellow diamond sign with the figure of a deer, as specified in the *Manual of Uniform Traffic Control Devices*.

No studies have evaluated the effectiveness of standard deer warning signs in increasing driver awareness of deer, in reducing driving speeds, or in reducing DVCs. Because passive signs are used so frequently at locations where deer are present only occasionally, drivers probably ignore them (Putman 1997, Sullivan and Messmer, 2003).

**Lighted and animated signs:** Three methods have been used to attempt to increase the effect of deer warning signs. The first is to make the signs more visible with lights, flags, or even a lighted and animated figure of a deer. In a small study of lighted and animated signs, Pojar et al. (1975) found a slight effect on vehicle speeds but no effect on DVCs.

**Temporary passive signs:** The second method, used on roads crossed by mule deer migration corridors, installs or uncovers passive signs only during migration periods. Messmer et al. (2000) used large warning signs with battery-powered flashing amber lights at the ends of a two-mile and a four-mile roadway section, together with smaller flashing signs at each milepost within the two sections. Travel speeds during three migration periods when the signs were displayed and activated dropped about 8 mph from pre-migration levels, and DVCs dropped by 50 percent in the spring and 70 percent in the fall migration compared with three previous years. In a more extensive study of the same technique, using a more powerful research design, Sullivan et al. (preprint) placed similar temporary lighted signs on five roadway sections in three states with an adjacent section, separated by a buffer section, as a control. DVCs were about 50 percent lower in signed than in control sections across all sites. Vehicle speeds also were lower in signed sections.

**Active signs:** The final method uses signs that are activated only when deer are detected near the roadway. Detection methods include infrared light (in Minnesota), radar (Wyoming), laser (Washington), radio frequency beams parallel to the roadway (Indiana), and heat detection cameras (British Columbia). In Washington, radio collars have been attached to 8 elk in a herd of 80 near a segment of Highway 101. Flashing “elk warning” signs are activated when any of the collared elk come within one-quarter mile of the roadway (DeerCrash, 2003).

The only evaluation of these methods to date is a small study of a segment of U.S. 30 in Nugget Canyon, Wyoming (Gordon et al., 2001). An eight-foot fence was erected along both sides of the roadway, with a 300-foot gap through which migrating deer could cross. Two deer detection systems were used: infrared heat sensors, and geophones that detect ground vibrations combined with infrared light beams that detect motion across the beam. Both systems detected almost all deer (very few false negatives). The heat sensor system also was activated by birds and snow (more than 50 percent false positives), while the combined geophone and infrared system had no false positives. Vehicle speeds dropped by about 4 mph when the “deer on road when lights are flashing” sign was lighted, regardless of whether the sign was triggered by a deer, a false positive, or remotely by a researcher. DVC data were not collected, and it is unclear whether the observed speed reduction would be large enough to affect DVCs.

In summary, standard passive signs, although low-cost and low-maintenance, are unlikely to have any effect, though no evaluations substantiate this conclusion. The one study of lighted signs showed no effect on DVCs. Initial results are encouraging for temporary passive signs used in defined mule deer migratory corridors during migratory periods, which can vary from year to year. More testing is needed before the potential of active signs can be evaluated accurately. The two main issues are to refine detection technology to minimize false positives and false negatives and to determine the effects of these signs on driver behavior and DVCs.

## **Deer Visibility**

The sooner a driver sees a deer on or approaching a roadway, the better the chance of avoiding a crash. Deer visibility can be improved through roadway lighting, roadside clearing, or methods to enhance drivers’ nighttime vision.

**Roadway lighting:** Roadway lighting is commonly used to improve driver vision in urban areas, freeway interchanges, and other potentially dangerous locations. Because most DVCs occur at night, roadway lighting is an obvious potential countermeasure. In the only study of the effect of roadway lighting on DVCs, Reed and Woodard (1981) studied a single three-quarter-mile section in Colorado using a one week on/one week off design. The lighting did not affect overall deer crossings or driving speeds, and the study was too small to detect an effect on DVCs.

Roadway lighting is expensive. Only two states reported using lighting to control DVCs (Romin and Bissonette, 1996). It is unlikely to be useful except in very specialized situations.

**Roadside clearing:** A broad clear roadside area allows drivers to see deer that may enter the road and reduces forage that may attract deer close to the roadway. Finder et al. (1999) found that the most important landscape or topographical feature predicting high DVC sites in Illinois was the distance between the roadway and forest cover. In a study in Norway, Jaren et al. (1991) found that a clear 20-30 meter strip reduced crashes between railway trains and moose by more than 50 percent. Putman (1997) and Bruinderink and Hazebroek (1996) recommend reducing forage near the roadside. Roadside clearing raises many issues beyond DVC control, such as the costs of acquiring roadside right-of-way and of maintaining a clear area, the potential safety benefits if trees adjacent to the roadway are removed, and the aesthetics of cleared areas along secondary roads.

**Infrared detection from vehicles:** A potential long-term strategy to improve drivers' night vision is to equip vehicles with infrared technology that can detect deer and other heat-emitting objects and transmit information to drivers on heads-up displays. These systems have been introduced recently in Cadillacs (General Motors, 2000) and as aftermarket equipment for heavy trucks (Bendix, 2002), but their effects on DVCs have not been evaluated. Any strategy involving vehicle modifications requires many years to implement in the majority of the vehicle fleet.

### **Speed Limits**

An approach often suggested to reduce traffic crashes in many situations is to attempt to reduce travel speeds through lower speed limits. Unfortunately, lower speed limits do not necessarily produce lower travel speeds (Transportation Research Board, 1998). The only study to evaluate the effects of speed limit changes on wildlife crashes involved short road segments in the highly regulated environment of Jasper National Park. Bertwistle (1999) compared sheep and elk crashes for eight years before and eight years after the speed limit was reduced from 90 to 70 km/h on three highway segments of 2.5 km, 4 km, and 9 km. He found that sheep crashes *increased* on these segments and decreased on adjoining segments where the speed limit remained at 90 km/h. Elk crashes increased on the speed-limit-reduction segments and increased more on the unchanged segments. No travel speed data were collected to measure the direct effect of the speed limit change. Bertwistle notes that differences in sheep and elk behavior likely explain the crash result differences.

Speed limit reductions together with deer warning signs may be useful in very specific locations with high deer populations or migration routes. However, unless speed limits are actively enforced, they are unlikely to affect travel speeds significantly, and perhaps not even then. Although seven states reported reducing speed limits in an attempt to control DVCs (Romin and Bissonette, 1996), the effects of these speed limit reductions have not been evaluated.

## METHODS TO AFFECT DEER BEHAVIOR

Deer behavior management strategies attempt to either physically block deer from the roadway or make the roadway less attractive to deer by appealing to their senses of sight, sound, or smell.

### Physical Control

**Fencing:** Fencing provides a physical barrier that attempts to prevent deer from entering the roadway. Every review of DVC control methods during the past 20 years has concluded that properly designed and maintained fencing, used together with appropriate underpasses, overpasses, and one-way deer gates, is the most effective method for reducing DVCs both in the United States (Danielson and Hubbard, 1998; Reed et al., 1979) and in Europe (Bruinderink and Hazebroek, 1996; Putman, 1997; Staines et al., 2001). State wildlife administrators agree, while state highway administrators rank fencing second to reducing deer herd size (Sullivan and Messmer, 2003). In 1992, 11 states had erected fencing to reduce DVCs (Romin and Bissonette, 1996). Crashes with moose were reduced by 80 percent after about 1,300 km of main roads in Sweden were fenced (Lavsund and Sandegren, 1991).

Aside from herd reduction, fencing is the only DVC method that unquestionably is effective if applied properly. Fencing that is sufficiently high, strong, long, and well-anchored with no gaps or tunnels will prevent deer from crossing a fenced road section. The issues with fencing involve the details and side effects.

- *Physical characteristics:* Fencing must be sufficiently high and long. Several studies have found 2.4 m (7.8 ft) fencing effective (Ward, 1982 (in Wyoming); Reed et al., 1982 (in Colorado); Ludwig and Bremicker, 1983 (in Minnesota)). White-tailed deer will jump a 2.2 m (7.4 ft) fence in search of food (Bellis and Graves, 1978). Fencing must extend far enough along a roadway to discourage deer from detouring around the ends of the fenced section. The necessary length depends on deer movement patterns. After one year's experience, Ward (1982) extended a fenced section from 6.7 to 7.8 miles and reduced end runs substantially. Electric fencing, currently being studied in Michigan, may provide an effective alternative to chain-link fencing (DVCR Working Group, 2000). Curtis et al. (1994) summarized the characteristics and effectiveness of various fencing types used to prevent deer from damaging crops.
- *Maintenance:* Regular checks are required to repair tunnels and breaks caused by erosion, animals, falling trees, and people. Deer regularly test a fence and are quick to pass through any breaks or gaps (Ward, 1982). Deer can crawl through openings less than 10 inches high under a fence (Bellis and Graves, 1978; Falk et al., 1978).
- *Effect on deer movements:* Fencing design should consider deer movement patterns and provide safe passage routes, as appropriate, through underpasses or other methods.



- *Escape routes:* Deer that manage to enter a fenced roadway need some way to escape. One-way gates have been found generally successful (Reed et al., 1974; Ward, 1982; Ludwig and Bremicker, 1983).
- *Costs:* Effective fencing is costly to construct and maintain. Iowa recently estimated construction costs for 8 ft chain-link fence on one side of a roadway at \$42,000 per mile (Danielson and Hubbard, 1998).
- *Other effects:* Roadway fencing or more substantial physical barriers may have other benefits such as reducing noise in adjacent properties or preventing pedestrian access to high-speed roads. Fencing and barriers may have positive or negative aesthetic implications.

**Underpasses and overpasses:** Deer underpasses, and more rarely used overpasses, allow deer to cross a roadway without encountering vehicles. Deer sometimes use underpasses or overpasses created when highways cross rivers or tunnel through ridges. Seven states report using underpasses specifically to allow deer crossings (Romin and Bissonette, 1996). Olbrich (1984) noted 824 under- and overpasses for animals on 823 km of federal highway in West Germany. To be effective, fencing or other barriers are required to channel deer to underpasses and overpasses.

Ward (1982) describes how a system of fencing and six underpasses was used along 7.8 miles of interstate highway crossing a mule deer migration route. The system did not disrupt deer movement and virtually eliminated DVCs. Other studies consider whether and how underpasses and overpasses are used rather than how they affect DVCs. Deer can be reluctant to use them, even when highly motivated to move along a migration route or to forage (Reed et al., 1975). Deer can remain wary or frightened even after several years of experience with the same underpass (Reed, 1981). Ward (1982) placed forage in underpasses to attract deer.

Factors affecting the use of underpasses and overpasses include their locations in relation to natural deer paths, size (wide openings and short lengths), design (earth floors), visual appearance (exit clearly visible from entrance, light walls and ceiling), and woody cover at the entrances (Danielson and Hubbard, 1998; Hartmann, 2003; Putman, 1997). In particular, some studies propose a minimum acceptable underpass “openness factor” of entrance area divided by underpass length (Putman, 1997).

Fencing and underpasses have been used to assist various species. Hartmann (2003) summarizes several case studies of underpass and overpass use by elk, bear, panther, mountain goats, and even salamanders. Singer and Doherty (1985) describe an underpass construction for mountain goats that directed almost all goats under rather than across the highway. Foster and Humphrey (1995) review other useful studies.

Underpasses and overpasses are expensive when included in original highway construction. Adding them to an existing highway is even more expensive.

**At-grade crosswalks:** Crosswalks may provide a middle ground between a fully separated underpass or overpass and uncontrolled crossings marked only with signs. In the only study to date, Lehnert and Bissonette (1997) installed nine crosswalks on about 13 miles of two-lane and 4 miles of divided four-lane highways in Utah, with similar adjacent roads used as controls. At each crosswalk, fencing and landscaping directed deer to the crosswalk area. Because fencing was not permitted on the highway shoulder, the deer were channeled to the highway on a dirt path bordered by cobblestones. A similar path bordered by cobblestones crossed the divided highway's median strip. White painted cattleguard lines bounded the path across the highway surface. One-way gates in the fencing near the crosswalks allowed deer that moved beyond the crosswalk area to leave the roadway. Passive signs warned drivers to expect deer in the crosswalk areas.

The crosswalks appeared to decrease DVCs by about 40 percent, although the small sample size precluded any definitive conclusions. The crosswalk design of cobblestones and cattleguard stripes directed many, but not all, deer across the road as intended. Although drivers may have been more alert for deer at crosswalk areas, fewer than 5 percent responded to crosswalk signs by slowing down or turning on their high-beam headlights.

Crosswalks may be worth additional study to determine if design improvements can contain deer more effectively and if active signs that detect deer in the crosswalk area can improve driver awareness and actions.

Crosswalks, underpasses, and overpasses are more likely to be effective for western mule deer than eastern white-tails. Mule deer have defined migratory routes across highways, so DVCs are confined to relatively few locations where these expensive control methods can be justified. In contrast, white-tailed deer crashes occur throughout substantial lengths of two-lane, rural roads (Maine Department of Transportation, 2002). Further, DVCs occur most frequently in the fall breeding season, when antlered males are chasing females. At these times, crosswalks or other methods short of the complete physical control provided by substantial fences are unlikely to keep deer off the highway.

### **Sensory Control**

**Reflectors:** Reflectors, used in Europe and some areas of the United States for more than 30 years, are the most contentious DVC control method. They have strong advocates, strong opponents, and conflicting results from more than 10 studies. The most commonly used and most frequently evaluated system, manufactured by Swareflex, consists of reflectors installed on posts at regular intervals along the roadway. Light from vehicle headlights is reflected to form a continuous "visual fence" of red, blue-green, or white light that deer are expected not to cross. Red reflectors form a visual barrier that humans cannot detect, so that it does not distract drivers. In 1992, 22 states reported using reflectors (Romin and Bissonette, 1997).

The basic behavioral questions about reflectors are whether deer can see light in the wavelengths used, whether deer are reluctant to cross such light beams, and whether deer become habituated to light beams over time. Zacks (1986) studied the effect of red and white light from Swareflex reflectors on penned white-tailed deer. He found no evidence that a beam of red or white light produced by reflectors from a static source, as opposed to a moving vehicle, affected deer behavior. Ujvari et al. (1998) exposed fallow deer in a large forested area to light from WEGU reflectors (a design similar to Swareflex) during a period of 15 nights. They found the proportion of deer that did not react to the reflected light increased over time: on the first night, 99 percent of the deer fled from low-intensity reflected light, while on the final three nights about 40 percent were completely indifferent to higher intensity light.

DeerCrash (2003) describes and summarizes 10 studies that attempt to evaluate the effect of roadside reflectors on DVCs using different study designs. The overall results are at best ambiguous.

- Four studies used designs that alternately cover and uncover the reflectors along a roadway segment. One found reflectors effective and three did not.
- Four studies used before/after designs. One found reflectors effective, one did not, and two had inconclusive results.
- Two studies used treatment/control designs. One found that reflectors were effective at some sites but not at others and the other study found no effect.

The best study in terms of its design, size, and power is Reeve and Anderson (1993), who used a cover/uncover design with control segments for three years on a 24.1 km segment of U.S. 30 in Wyoming that crosses a major mule deer migration route. They recorded 126 DVCs when the reflectors were uncovered, 64 when covered, and 147 on control segments. They concluded that the reflectors had no effect on DVCs.

Schafer and Penland (1985) provide the most positive site-specific evidence of effectiveness. They studied four roadway sections totaling 3.68 km in Washington during three years, in an area populated largely by white-tailed deer. They also used a cover/uncover design but with no control segments. They recorded 52 DVCs when reflectors were covered and only 6 when uncovered, concluding that the reflectors were highly effective.

Pafko and Kovach (1996) summarize results from a larger but less controlled application in Minnesota. Reflectors were installed at 16 road segments totaling 16.35 miles, four segments each in coniferous forest, prairie farmland, central hardwood, and metropolitan hardwood habitats. Average annual DVC counts on these segments for several years before and seven years after installation show 79 to 90 percent reductions in DVCs in the three rural habitats from pre-installation DVC averages of 98 to 214. In the metropolitan habitat, DVCs increased by 87 percent from a pre-installation average of 11.8.

These three examples illustrate the difficulties of drawing definitive conclusions from even the best studies. The very substantial reductions from high DVC totals found by Pafko and Kovach (1996)

suggest significant effects even though their simple before/after design does not control for other factors that may influence DVCs and their DVC counts may not be completely accurate. However, the authors note that estimated statewide deer populations were increasing during the study, DVCs did not decrease substantially on other roads, and the reductions appeared stable for several years. The increase in metropolitan areas may be due to small sample sizes, traffic volume increases, or reflector ineffectiveness on heavily traveled roads. Reeve and Anderson (1993) and Schafer and Penland (1985) reach very different conclusions from similar studies. Schafer and Penland had a considerably smaller study, with no control area, in an area populated largely by whitetails, while Reeve and Penland's study was on a mule deer migratory route.

If reflectors are effective, they offer obvious advantages. They are cheaper to install and maintain than physical barriers created with fencing and underpasses, though their cost is not insignificant — an estimated \$8,000 to \$10,000 per mile for installation (Danielson and Hubbard, 1998) plus annual maintenance to repair or replace damaged reflectors. Reflectors form a barrier only when vehicle headlights are present, so they allow deer to cross roads freely during daylight hours. However, the evaluations to date leave many questions unanswered. There appears to be no solid behavioral evidence that deer are reluctant to cross a light beam produced by reflectors. Do deer cross a beam at will, as suggested by Zacks (1986)? Do deer become habituated to such a beam, as found by Ujvari et al. (1998)? Are reflectors effective on high-volume roadways where there are few breaks in traffic to permit deer to cross? Are they effective on migratory routes or low-volume roads through established range areas where deer move freely?

Simple metal mirrors to reflect vehicle headlights as white light flashes also have been installed in a manner similar to reflectors. It appears that deer rapidly become accustomed to them, and they corrode quickly (Gilbert, 1982; Putman, 1997). Lavsund and Sandegren (1991) concluded from a large experiment that mirrors had no effect whatsoever on moose crashes in Sweden.

**Flagging:** An early attempt to influence deer behavior through sight was based on the observation that white-tailed deer raise their tails as a warning sign to other deer. Graves and Bellis (1978) placed rear-view silhouette models of deer with raised tails along a highway. These deer flag models did not affect deer movements (see also DeerCrash, 2003).

**Whistles:** Deer warning whistles have been available to the public for more than 20 years. A typical whistle is attached to a vehicle and produces ultrasonic noise in the range of 16-20 kHz when vehicle speed exceeds about 30 mph (DeerCrash, 2003). Whistles are based on the presumption that deer can hear and will be warned away from noise in this range. Twenty states reported using whistles in 1992 (Romin and Bissonette, 1997), although state wildlife agency and transportation department administrators ranked whistle effectiveness lowest of all common methods (Sullivan and Messmer, 2003).

Romin and Dalton (1992) conducted the only high-quality study of whistle effects. They drove past 150 groups of deer at distances up to 100 meters and a speed of 65 km/h, observing deer behavioral responses. Two common brands of whistles had no effect on deer behavior, even when deer were within 10 meters of the road. Romin and Dalton were unaware of any research demonstrating that deer are frightened by sound in the range produced by whistles. In a review of the effects of sound on animals and birds of many species, Bomford and O'Brien (1990) concluded that sounds of the type produced by whistles (steady noise rather than specific alarm or distress signals) may influence movements in the short term but that mammals and birds become accustomed to these sounds after long or frequent exposure.

Several less scientific reports and considerable anecdotal evidence either support or deny the effectiveness of whistles. For example, Cline (1989) reported on a one-year test of whistles attached to 42 Michigan State Police vehicles in five locations; 43 vehicles in five other locations served as controls. There were 14 DVCs involving police vehicles in the test locations and 5 in the control locations during the prior year; during the experimental year, there were 5 DVCs in each location. Based on these results, Cline concluded that the whistles were effective.

Roadside whistles, as opposed to vehicle-mounted whistles, are being tested in Saskatchewan (Beaupré, 2002). A series of noisemaking devices together with vehicle detection sensors was mounted along a 5 km section of highway. When the sensors detect a vehicle, the device warns deer with either sound or light signals.

In summary, there is no firm evidence that whistles are effective and considerable evidence that they are not. In the only high-quality study (Romin and Dalton, 1992), deer were not affected by whistles. It is unclear whether deer can hear whistles, whether whistle noise is covered by traffic noise, or whether deer become accustomed to whistle noise over time. In the absence of any solid studies that whistles are effective, they cannot be recommended.

**Repellents:** Chemical and biological substances attempt to repel deer in two ways. Contact repellents with unpleasant tastes applied to a food source seek to reduce or eliminate feeding. Area repellents with unpleasant smells, such as predator urine, seek to prevent deer from entering or crossing an area.

Several studies, summarized in El Hani and Conover (1995) and DeerCrash (2003), evaluated the effectiveness of various repellents on the feeding patterns of white-tailed and mule deer. Some repellents reduced feeding, but none completely stopped deer from feeding or entering an area.. The studies also showed that deer habituate to repellents and will not be deterred by them if sufficiently hungry. No study in the United States has evaluated the effects of repellents in reducing DVCs, and repellents are not used systematically in any state to control DVCs (Romin and Bissonette, 1996). Putman (1997) reported that repellent "scent fences" have been studied in Germany, with mixed results. Early results from a repellent "odor fence" installed along 53 km of roadway in British Columbia, using posts and boxes every 0.25 km,

reportedly showed a 36 percent DVC reduction from the prior 10 years, and a test of four different repellents along 16 km of roadway on Vancouver Island began in 1999 (DVCR Working Group, 2000).

Repellents are most likely to hinder deer movements when applied in conjunction with fences or other physical barriers (Curtis et al., 1994). Jordan and Richmond (1992) demonstrated that an electric fence treated with repellents was more effective in deterring deer from feeding on apples than an electric fence alone, although repellent effectiveness decreased significantly after several weeks. The combination of repellents and fences has proved useful for home gardens and agricultural fields (Curtis et al., 1994) but would be expensive to install and maintain along highways.

**Intercept feeding:** In certain locations, deer regularly cross roadways to feed. Wood and Wolfe (1988) studied three such road sections in Utah for two years. On the treatment portion of each section, they established and maintained feeding stations more than 1,200 feet away from the roadway. They found lower DVCs in some, but not all, treatment areas. They noted that a feeding program has continuing costs, may make deer dependent on the food provided, and may attract more deer to the roadside. They concluded that intercept feeding may be useful only temporarily in specific situations.

**Salt alternatives:** Some authors suggest that deer may be attracted to roadways by salt applied to melt ice in the winter and that other deicing substances should be used instead (Feldhamer et al., 1986; DeerCrash, 2003). However, no studies have investigated the issue.

## **METHODS TO AFFECT DEER POPULATIONS**

If there were no deer, or no deer near highways, there would be no DVCs. Deer herd reduction has long been considered an appropriate strategy for reducing DVCs as well as crop and garden losses caused by deer (DeNicola et al., 2000). State transportation department administrators rated herd management as potentially the most effective DVC control strategy, while state wildlife administrators rated it second only to fencing (Sullivan and Messmer, 2003).

The only herd reduction strategy that would completely eliminate DVCs would be to eliminate all deer, which the general public would not accept. Indeed, even in a high DVC area, only a minority of the public wished to reduce the deer population (Stout et al., 1993). In a survey of 10 randomly selected large metropolitan areas, 63 percent of respondents wanted no change in the number of deer in their neighborhoods, 27 percent wanted more deer, and only 10 percent wanted fewer deer (Conover, 1997).

Two reports document how local deer herd management policies can affect DVCs. In 1972, Princeton, New Jersey, passed a no-firearms-discharge ordinance. DVCs then increased by 436 percent in 10 years, from 33 in 1972 to 144 in 1982, compared with no statistically significant change in two adjoining townships where firearms hunting continued to be allowed (Kuser, 1995). Princeton then tried to reduce DVCs and other deer-related problems with deer whistles, reflectors, and increased bowhunting, but DVCs continued to rise, to 167 in 1991 and 227 in 1992.

Irondequoit, New York, began a selective deer culling and bowhunting program in 1993. About 125 deer were removed in each of the next eight years. DVCs dropped from 227 in 1992 to about 100 annually in the late 1990s (Eckler, 2001).

Although herd reduction can be controversial, common sense and expert opinion agree that substantial and continued herd reductions will reduce DVCs (Danielson and Hubbard 1998; DVCR Working Group, 2000). But many questions remain, including the effectiveness of herd reductions over a large area on DVCs, the amount of herd reduction necessary to reduce DVCs substantially, how deer range and migration patterns influence the effect of herd reductions on DVCs, and how to design cost-effective herd reduction programs (Brown et al., 2000). Wisconsin and other states are pursuing aggressive deer herd reduction programs (DVCR Working Group, 2000). Data from these programs may help address these questions.

## **SUMMARY AND CONCLUSIONS**

### **Effective Methods with Solid Scientific Evidence**

Fencing, combined with underpasses and overpasses as appropriate, is the only broadly accepted method that is theoretically sound and proven to be effective. Fencing is expensive to construct and maintain, and even the best fencing will not prevent all deer from entering a roadway.

### **Promising Methods Where More Information Is Needed**

Herd reduction is unquestionably effective in reducing DVCs if the deer population in a specific area is reduced by a substantial amount. More research is needed on the minimum area needed for herd reduction to have a substantial effect and on the expected impact of a given amount of herd reduction on DVCs. A herd reduction strategy should be part of an overall wildlife management program that balances the costs and benefits of maintaining wildlife populations.

Roadside clearing may be effective, although there is very limited information supporting it. Roadside clearing must be part of a broader strategy of roadway design and maintenance.

Both temporary passive signs and active signs appear promising in specific situations, but considerable research is required to evaluate long-term driver response and to improve and test deer detection technology for active signs.

At-grade crossings for deer, perhaps combined with active signs, offer a long-shot chance at providing greater safety than uncontrolled crossings marked only with passive signs. At-grade crossings are most promising for highways crossing mule deer migration routes in western states.

Infrared driver vision technology in vehicles may be effective in the future. Its development and implementation will depend on its usefulness in improving driver night vision overall, not on its effect on DVCs.

### **Methods With Limited Demonstrated Effectiveness**

Although reflectors have been studied fairly often, most studies were not designed or conducted well. The balance of the available evidence is that reflectors have little long-term effect, especially for white-tailed deer in suburban areas. Additional high-quality studies would be useful to investigate deer response and habituation to light beams and the effectiveness of reflectors when implemented.

Roadside lighting and intercept feeding may have limited effectiveness in specialized situations. Both methods are costly and have side effects that must be considered carefully.

Deer repellents can have limited effectiveness in modifying deer feeding and movement patterns. It is unlikely that repellents will be useful in roadway applications.

### **Methods that Appear Ineffective Based on Available Evidence**

General education, passive signs, and lower speed limits appear ineffective in influencing driver behavior and reducing DVCs. The lack of good studies proving their ineffectiveness probably results from the unwillingness of funding organizations to allocate resources to study methods that are so unpromising.

### **Ineffective Methods with Evidence from Controlled or Experimental Situations**

Deer whistles and deer flagging signs are not effective.

## **DISCUSSION AND RECOMMENDATIONS**

Previous reviews of DVC control methods (Reed et al., 1979; Bruinderink and Hazebroek, 1996; Putman, 1997; Danielson and Hubbard, 1998; Staines et al., 2001) reached conclusions similar to ours, as did a review of moose-vehicle crashes in Sweden (Lavsund and Sandegren, 1991). There is no quick, cheap method to reduce DVCs. Fencing and herd reduction programs can be effective if they are designed and maintained well, but they are neither cheap nor quick.

DVC control must be part of an overall environmental strategy that balances the competing needs of humans and wildlife. For example, there is a trend in suburban areas to preserve or create green space and wildlife corridors (Houck, 1990). These areas must be carefully planned and coordinated by transportation, natural resource, and urban planning agencies to avoid attracting more deer and increasing DVCs.

### **Data Collection and Reporting**

States should identify crashes involving deer on their state crash report forms and crash data files rather than aggregating crashes involving all animals. Without this, it is difficult to track DVC totals, trends, and patterns. States also should record precise DVC locations, as Maine does (Maine Department of Transportation, 2002), using GIS or other methods, to identify areas with high DVC frequencies. This



information is critical in deciding where fencing, herd reduction, active signs, or other DVC control methods are needed.

## Research

Research is needed in the following areas.

- *Herd reduction*: minimum geographic area needed to be effective, effect of different amounts of herd reduction on DVCs in various settings
- *Active signs*: improved deer detection technology, long-term driver response
- *Temporary passive signs and at-grade crossings*: additional field trials under varying circumstances
- *Reflectors*: deer response and habituation, effect of reflector systems as implemented
- *Intensive general education*: effects of intensive driver awareness programs for DVCs in targeted communities
- *Integrated DVC program*: effects of coordinated program including signs, roadside clearing, and general education in specific high DVC locations
- *Data*: multi-state survey of DVC reporting to police, insurance companies, and wildlife agencies

## ACKNOWLEDGMENTS

This study was supported by the Insurance Institute for Highway Safety. The opinions, findings, and conclusions are those of the authors and do not necessarily reflect the views of the Insurance Institute for Highway Safety.

## REFERENCES

- Allen, R.E. and McCullough, D.R. 1976. Deer-car accidents in southern Michigan. *Journal of Wildlife Management* 40:317-25.
- Beaupré, V.G. 2002. Pilot project to deter wildlife-vehicle collisions. Press release. Regina, Saskatchewan: Saskatchewan Department of Highways and Transportation. Available: <http://www.gov.sk.ca/newsrel/releases/2002/05/09-326.html>.
- Bellis, E.D. and Graves, H.B. 1978. Highway fences as deterrents to vehicle-deer collisions. *Transportation Research Record* 674:53-58. Washington, DC: Transportation Research Board.
- Bendix. 2002. Bendix begins sale of XVision™ infrared nighttime vision system. Press release. Elyria, OH. Available: <http://www.bendix.com/products/XVisionPR.shtml>.
- Bertwistle, J. 1999. The effects of reduced speed zones on reducing bighorn sheep and elk collisions with vehicles on the Yellowhead Highway in Jasper National Park. *Proceedings of the 1999 International Conference on Wildlife Ecology and Transportation*. Tallahassee, FL: Florida Department of Transportation.

- Bomford, M. and O'Brien, P.H. 1990. Sonic deterrents in animal damage control: a review of device tests and effectiveness. *Wildlife Society Bulletin* 18:411-22.
- Brown, T.L.; Decker, D.J.; Riley, S.J.; Enck, J.W.; Lauber, T.B.; Curtis, P.C. and Mattfeld, G.F. 2000. The future of hunting as a mechanism to control white-tailed deer populations. *Wildlife Society Bulletin* 28:797-807.
- Bruinderink, G.W.T.A. and Hazebroek, E. 1996. Ungulate traffic collisions in Europe. *Conservation Biology* 10:1059-67.
- Cline, B.C. 1989. The State of Michigan's Car-Deer Whistle Research Project. Lansing, MI: Michigan Department of Management and Budget.
- Conover, M.R. 1997. Wildlife management by metropolitan residents in the United States: practices, perceptions, costs, and values. *Wildlife Society Bulletin* 25:306-11.
- Conover, M.R.; Pitt, W.C.; Kessler, K.K.; DuBow, T.J. and Sanborn, W.A. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. *Wildlife Society Bulletin* 23:407-14.
- Curtis, P.D.; Fargione, M.J. and Richmond, M.E. 1994. Preventing deer damage with barrier, electrical, and behavioral fencing systems. *Proceedings of the 16th Vertebrate Pest Conference* (eds. W.S. Halverson and A.C. Crabb), 16:223-227. Davis, CA: University of California, Davis
- Danielson, B.J. and Hubbard, M.W. 1998. A literature review for assessing the status of current methods of reducing deer-vehicle collisions. Ames, IA: Iowa Department of Transportation and Iowa Department of Natural Resources.
- Decker, D.J.; Loconti Lee, K.M. and Connelly, N.A. 1990. Deer-related vehicular accidents in Tompkins County, New York: incidence, costs, and implications for deer management *Transactions of the Northeast Section of the Wildlife Society* 47:21-26.
- DeerCrash. 2003. Countermeasures toolbox. Madison, WI: University of Wisconsin, Madison, Deer-Vehicle Crash Information Clearinghouse. Available: <http://www.deercrash.com/toolbox/index.htm>.
- DeNicola, A.J.; VerCauteren, K.C.; Curtis, P.D. and Hyngstrom, S.C. 2000. *Managing White-Tailed Deer in Suburban Environments: A Technical Guide*. Ithaca, NY: Cornell Cooperative Extension.
- DVCR Working Group. 2000. Final Report: Deer Vehicle Collision Reduction Working Group Conference. Madison, WI: Sand County Foundation.
- Eckler, J. 2001. Irondequoit Live Deer Spotlight Survey, Fall 2000. Albany NY: New York State Department of Environmental Conservation.
- El Hani, A. and Conover, M.R. 1995. Comparative analysis of deer repellents. *Repellents in Wildlife Management Symposium Proceedings*. Fort Collins, CO: National Wildlife Research Center, Animal and Plant Health Inspection Service.
- Falk, N.W.; Graves, H.B. and Bellis, E.D. 1978. Highway right-of-way fences as deer deterrents. *Journal of Wildlife Management* 42:646-50.
- Feldhamer, G.A.; Gates, J.E.; Harman, D.M.; Loranger, A.J. and Dison, K.R. 1986. Effects of interstate highway fencing on white-tailed deer activity. *Journal of Wildlife Management* 50:497-503.

- Finder, R.A.; Roseberry, J.L. and Woolf, A. 1999. Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. *Landscape and Urban Planning* 44:77-85.
- Foster, M.L. and Humphrey, S.R. 1995. Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin* 23:95-100.
- General Motors. 2000. DeVile becomes first car to offer safety benefits of night vision. Detroit, MI. Available: [http://www.gm.com/company/gmability/safety/crash\\_avoidance/newfeatures/night\\_vision.html](http://www.gm.com/company/gmability/safety/crash_avoidance/newfeatures/night_vision.html).
- Gilbert, J.R. 1982. Evaluation of deer mirrors for reducing deer-vehicle collisions. Report no. FHWA-RD-82-061. Washington, DC: Federal Highway Administration.
- Gordon, K.M.; Anderson, S.H.; Gribble, B. and Johnson, M. 2001. Evaluation of the FLASH (Flashing Light Animal Sensing Host) system in Nugget Canyon, Wyoming. Report no. FHWA-WY-01/03F. Laramie, WY: University of Wyoming.
- Graves, H.B. and Bellis, D.E. 1978. The effectiveness of deer flagging models as deterrents to deer entering highway rights-of-way. Report no. FHWA-PA-78-12. Washington, DC: Federal Highway Administration.
- Hartmann, M. 2003. Evaluation of wildlife crossing structures: their use and effectiveness. Missoula, MT: Wildlands Center for Preventing Roads. Available: <http://www.wildlandscpr.org/resourcelibrary/reports/EvaluationByMaureenHartmann.htm>.
- Houck, M.C. 1990. Metropolitan wildlife refuge system: a strategy for regional natural resource planning. *Wildlife Conservation in Metropolitan Environments* (eds. L.W. Adams and D.L. Leedy), 225-29. Columbia, MD: National Institute for Urban Wildlife.
- Highway Safety Information System. 1995. Investigation of crashes with animals. Report no FHWA-RD-94-156. Washington, DC: Federal Highway Administration.
- Hubbard, M.W.; Danielson, B.J. and Schmitz, R.A. 2000. Factors influencing the location of deer-vehicle accidents in Iowa. *Journal of Wildlife Management* 64:707-13.
- Jaren, V.; Andersen, R.; Ulleberg, M.; Pedersen, P.H. and Wiseth, B. 1991. Moose-train collisions: the effects of vegetation removal with a cost-benefit analysis. *Alces* 27:93-99.
- Jordan, D.M. Jr. and Richmond, M.E. 1992. Effectiveness of a vertical 3-wire electrical fence modified with attractants or repellents as a deer enclosure. *Proceedings of the Fifth Eastern Wildlife Damage Control Conference*, 44-47.
- Knapp, K. 2001. Midwest deer-vehicle crash facts. Madison, WI: University of Wisconsin, Madison, Deer-Vehicle Crash Information Clearinghouse.
- Knox, W.M. 1997. Historical changes in the abundance and distribution of deer in Virginia. *The Science of Overabundance* (eds. W.J. McShea, H.B. Underwood, and J.H. Rappole). Washington, DC: Smithsonian Institution Press.
- Kuser, J. 1995. Deer and people in Princeton, New Jersey, 1971-1993. *Urban Deer: A Manageable Resource? Proceedings of the 1993 Symposium of the North Central Section, the Wildlife Society* (ed. J.B. McAninch), 47-50.
- Lavsund, S. and Sandegren, F. 1991. Moose-vehicle relations in Sweden: a review. *Alces* 27:118-26.

- Lehnert, M.E. and Bissonette, J.A. 1997. Effectiveness of highway crosswalk structures at reducing deer-vehicle collisions. *Wildlife Society Bulletin* 25:809-18.
- Ludwig, J. and Bremicker, T. 1983. Evaluation of 2.4m fences and one-way gates for reducing deer-vehicle collisions in Minnesota. *Transportation Research Record* 913:19-22. Washington, DC: Transportation Research Board.
- Maine Department of Transportation. 2002. Maine deer crashes, 1999-2001. Augusta ME: Maine Department of Transportation.
- McCabe, T.R. and McCabe, R.D. 1997. Recounting whitetails past. *The Science of Overabundance* (eds. W.J. McShea, H.B. Underwood, and J.H. Rappole). Washington, DC: Smithsonian Institution Press.
- Messmer, T.A.; Hendricks, C.W. and Klimack, P.W. 2000. Modifying human behavior to reduce wildlife-vehicle collisions using temporary signage. *Wildlife and Highways: Seeking Solutions to an Ecological and Socio-Economic Dilemma – Seventh Annual Meeting of the Wildlife Society*, 134-47.
- Olbrich, P. 1984. Untersuchung der Wirksamkeit von Woldwarnreflektoren und der Eignung von Wilddurchlassen. *Zeitschrift für Jagdwissenschaft* 30:101-16.
- O'Neill, B. 2001. Seat belt use: where we've been, where we are, and what's next. *2001 Seat Belt Summit: Policy Options for Increasing Seat Belt Use in the United States in 2001 and Beyond*, Appendix A. Arlington, VA: Automotive Coalition for Traffic Safety.
- Pafko, F. and Kovach, B. 1996. Minnesota experience with deer reflectors. *Proceedings of Transportation and Wildlife: Reducing Wildlife Mortality and Improving Wildlife Passageways Across Transportation Corridors*, 116-124. Tallahassee, FL: Florida Department of Transportation.
- Pojar, T.M.; Reed, D.F.; Reseigh, T.C. and Woodard, T.N. 1975. Effectiveness of a lighted, animated deer crossing sign. *Journal of Wildlife Management* 39:87-91.
- Puglisi, M.J.; Lindzey, J.S. and Bellis, E.D. 1974. Factors associated with highway mortality of white-tailed deer. *Journal of Wildlife Management* 38:799-807.
- Putman, R.J. 1997. Deer and road traffic accidents: options for management. *Journal of Environmental Management* 51:43-57.
- Reed, D.F. 1981. Mule deer behavior at a highway underpass exit. *Journal of Wildlife Management* 45:542-43.
- Reed, D.F.; Beck, T.D. and Woodard, T.N. 1982. Methods of reducing deer-vehicle accidents: benefit-cost analysis. *Wildlife Society Bulletin* 10:349-54.
- Reed, D.F.; Pojar, T.M. and Woodard, T.N. 1974. Use of one-way gates by mule deer. *Journal of Wildlife Management* 38:9-15.
- Reed, D.F. and Woodard, T.N. 1981. Effectiveness of highway lighting in reducing deer-vehicle collisions. *Journal of Wildlife Management* 45:721-26.
- Reed, D.F.; Woodard, T.N. and Beck, T.D.I. 1979. Regional deer-vehicle accident research. Report no. FHWA-CO-RD-79-11. Denver, CO: Colorado Division of Wildlife.
- Reed, D.F.; Woodard, T.N. and Pojar, T.M. 1975. Behavioral response of mule deer to a highway underpass. *Journal of Wildlife Management* 39:361-67.

- Reeve, A.F. and Anderson, S.H. 1993. Ineffectiveness of Swareflex reflectors at reducing deer-vehicle collisions. *Wildlife Society Bulletin* 21:127-32.
- Romin, L.A. and Bissonette, J.A. 1997. Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. *Wildlife Society Bulletin* 24:276-83.
- Romin, L.A. and Dalton, L.B. 1992. Lack of response by mule deer to wildlife warning whistles. *Wildlife Society Bulletin* 20:382-84.
- Schafer, J.A. and Penland, S.T. 1985. Effectiveness of Swareflex reflectors in reducing deer-vehicle accidents. *Journal of Wildlife Management* 49:774-76.
- Singer, F.J. and Doherty, J.L. 1985. Managing mountain goats at a highway crossing. *Wildlife Society Bulletin* 13:469-77.
- Staines, B.; Langbein, J. and Putman, R. 2001. Road traffic accidents and deer in Scotland. Aberdeen, UK: University of Aberdeen.
- Stout, R.J.; Stedman, R.C.; Decker, D.J. and Knuth, A.B. 1993. Perception of risk from deer-related vehicle accidents: implications for public preferences for deer herd size. *Wildlife Society Bulletin* 21: 237-49.
- Sullivan, T.L. and Messmer, T.A. 2003. Perceptions of deer-vehicle collision management by state wildlife agency and department of transportation administrators. *Wildlife Society Bulletin* 31:163-73.
- Sullivan, T.L.; Williams, A.F.; Messmer, T.A.; Nelson, L.A. and Kyrychenko, S.Y. 2003. Effectiveness of temporary warning signs in reducing deer-vehicle collisions during mule deer migrations (preprint). Arlington, VA: Insurance Institute for Highway Safety.
- Transportation Research Board. 1998. Managing speed: review of current practice for setting and enforcing speed limits. Special Report 254. Washington, DC: Transportation Research Board.
- Ujvari, M.; Baagoe, H.J. and Madsen, A.B. 1998. Effectiveness of wildlife warning reflectors in reducing deer-vehicle collisions: a behavioral study. *Journal of Wildlife Management* 62:1094-99.
- Ward, A.L. 1982. Mule deer behavior in relation to fencing and underpasses on Interstate 80 in Wyoming. *Transportation Research Record* 859:8-13. Washington, DC: Transportation Research Board.
- Williams, A.F. 1994. The contribution of education and public information to reducing alcohol-impaired driving. *Alcohol, Drugs, and Driving* 10:197-205.
- Williams, A.F. 2003a. Motor vehicle/animal collisions. Internal memorandum. Arlington, VA: Insurance Institute for Highway Safety.
- Williams, A.F. 2003b. Personal communication.
- Wood, P. and Wolfe, M.L. 1988. Intercept feeding as a means of reducing deer-vehicle collisions. *Wildlife Society Bulletin* 16:376-80.
- Zacks, J.L. 1986. Do white-tailed deer avoid red? An evaluation of the premise underlying the design of Swareflex wildlife reflectors. *Transportation Research Record* 1075:35-43. Washington, DC: Transportation Research Board.