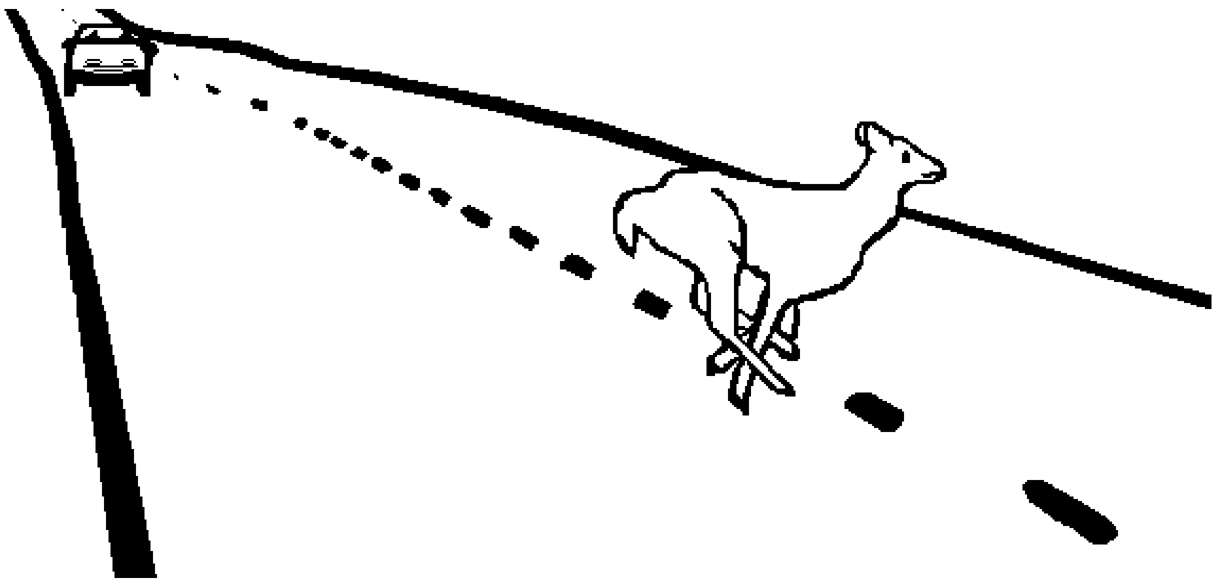
# A LITERATURE REVIEW FOR ASSESSING THE STATUS OF CURRENT METHODS OF REDUCING DEER-VEHICLE COLLISIONS

by



Dr. Brent J. Danielson
Dr. Michael W. Hubbard

a report prepared for

The Task Force on Animal Vehicle Collisions,
The Iowa Department of Transportation,
and
The Iowa Department of Natural Resources

July 1998

# A LITERATURE REVIEW FOR ASSESSING THE STATUS OF CURRENT METHODS OF REDUCING DEER-VEHICLE COLLISIONS

by

Dr. Brent J. Danielson

Dr. Michael W. Hubbard

a report prepared for

The Task Force on Animal Vehicle Collisions,
The Iowa Department of Transportation,
and
The Iowa Department of Natural Resources

Submitted September 1998

## ACKNOWLEDGMENTS

The authors wish to express their thanks to the numerous individuals who provided information regarding animal-vehicle collision publications.  Special thanks is extended to those companies and individuals that provided product information, estimated costs, construction feasibility and advice for locating information on product development.

## TABLE OF CONTENTS

## GENERAL INFORMATION

Animal-vehicle collisions on roadways have probably occurred since the advent of the automobile. Wildlife mortality associated with roadways has continually increased during the 20$^{th}$ century as vehicle speed and traffic volumes have increased (Puglisi et al. 1974).

In 1980, Williamson (1980) reported that 200,000 deer were killed on U.S. roadways in deer-vehicle collisions. Deer-vehicle collisions have increased significantly since 1980 (Romin and Bissonette 1996). In 1991, an estimate of more than 538,000 deer were killed by vehicles in the United States (Romin and Bissonette 1996). This estimate was considered conservative since numerous hits were not recorded (Lehnert and Bissonette 1997) and it was an estimate of only 36 states. Conover et al. (1995) estimated that 726,000 deer-vehicle accidents occur annually in the U.S. In Iowa alone, an estimated 11,000 deer-vehicle collision occurred in 1995 (Iowa Department of Natural resources, unpubl. data).

Animal-vehicle collisions are not only a traffic problem in North America. Animal-vehicle collisions are also considered a major safety problem in both Japan and Europe (Bruinderink and Hazebroek 1996, Stout et al. 1993). In Europe, excluding Russia, an estimated 507,000 ungulate-vehicle accidents occur annually (Bruinderink and Hazebroek 1996).

Since the number of deer-vehicle collisions can be estimated, the risk of personal injury and economic costs of those collisions can also be estimated. Human injuries occurred in less than 4% of deer-vehicle collisions in Michigan and were usually the result of secondary collisions (Allen and McCullough 1976). In West Germany in 1982, 20 people were killed and 1500 injured in animal vehicle collisions (Putman 1997). In Europe, excluding Russia, ungulate-vehicle accidents result in 300 human fatalities and 1 billion U.S. dollars in property damage (Bruinderink and Hazebroek 1996). The Federal Highway Administration has placed a value of $1.5 million on each human fatality (Romin and Bissonette 1996). Nationwide insurance (1993) estimated 120 people/year were killed in animal vehicle accidents. In 1978, the average cost of a deer-vehicle collision in Michigan was estimated at $648 (Hansen 1983). In Iowa, by 1996, the average cost of a deer-vehicle collision had risen to over $1,000 (J. Whylie, claims supervisor, State Farm Insurance, pers. comm). Nationwide, the average vehicle damage costs have been estimated at approximately $2,000 per collision. Conover et al. (1995) estimated that in the United States, deer-vehicle accidents result in 29,000 human injuries, 211 human fatalities, and over $1 billion (Conover 1997*a*) in property damage annually.

In Iowa, approximately 25% of all vehicle accidents in rural areas are animal related. In recent years, over 11,000 deer-vehicle collisions have occurred on Iowa roadways annually (50% increase in past 5 yr), resulting in over $10,000,000 in personal injury and property damage per year.

Conover (1997*a*) indicated that deer may provide more value to society than any other North American wildlife species with a net monetary value of over $12 billion annually. Sportsmen expend over $72,000,000 annually in pursuit of white-tailed deer in Iowa (U.S. Department of Interior). Unfortunately, determining the monetary value of a single deer is difficult because deer are owned by society rather than individuals (Conover 1997*a*). However, an Iowa survey in the mid-1980s estimated a deer's value at $600 (W. Suchy, IDNR Deer Research Biologist, pers. comm). In 1996, Romin and Bissonette concluded that a single deer had a monetary value of $1,313. In a Michigan study, over 90% of deer-vehicle collisions resulted in deer fatalities (Allen and McCullough 1976). If, as Conover et al. (1995) estimates, 726,000 deer-vehicle accidents occur annually, the estimated economic loss of deer to highway accidents in the United States approaches $1 billion annually. The combined annual economic loss to the United States from deer-vehicle collisions exceeds $2 billion annually in property damage, human casualties, and animal fatalities. In Iowa alone, the combined cost of deer-vehicle collisions to society ranges from $17,600,000 to $25,440,000 annual depending on the value($600 vs. $1,313) of the deer (Iowa courts have recently raised the fine for illegal harvest of antlered white-tailed deer to $3,000/animal).

Even though large numbers of deer-vehicle collisions occur annually, determining the cause of these accidents has proven difficult. High vehicle speed is considered one of the main causes of animal-vehicle accidents (Pojar et al. 1975, Case 1978). High occurrences of road kills has also been associated with animal characteristics such as dispersal and breeding activities (Case 1978, Feldhamer et al. 1986). Unfortunately, animal-vehicle accident rates "do not relate simply to animal numbers, neither do they relate solely to traffic volume" (Bruinderink and Hazebroek 1996). For example, in the Netherlands, over the past 20 years, roe deer and traffic volumes increased by factors of 2.2 and 1.5, respectively, but deer-vehicle accidents rose by a factor of 10 (Bruinderink and Hazebroek 1996). They concluded that changes in ungulate populations and traffic volume and their effect on animal-vehicle collisions were often ambiguous (Bruinderink and Hazebroek1996).

Regardless of the reasons for deer-vehicle collisions, determining methods for reducing those accidents is important to the public and state and federal transportation agencies throughout the country. Animal-vehicle collisions amount to a significant annual monetary total, however, the relative effectiveness and cost of different deterrent methods is poorly understood (Putman 1997). Published literature on methods used to reduce deer-vehicle collisions is limited, and most of that literature is in non-peer reviewed state agency publications (Romin and Bissonette 1996).

Techniques selected to reduce animal-vehicle collision are often arbitrary, without any follow-up analysis of their effectiveness (Putman 1997). Romin and Bissonette (1996) stated that of the various techniques used in attempts to reduce deer-vehicle collisions, "few rigorous evaluations regarding the effectiveness of these techniques exist; yet they continue to be used. In most cases, evaluation of success were based on opinion, hardly a solid foundation upon which to base successful remedial management actions." Putman (1997) indicated that selection of appropriate measures for reducing deer-vehicle collisions is dependent on understanding the actual pattern of those accidents. "Without such biological understanding, we cannot really determine where preventative measures should be concentrated, or suggest, *a priori*, which of a variety of deterrent options is likely to be most effective in given circumstances" (Putman 1997).

In the past, most states have attempted to address the increased occurrences of deer-vehicle collisions. Romin and Bissonette (1996) reported that nearly all states in the U.S. have used some technique in an attempt to reduce deer-vehicle accidents, but few agencies had evaluated their performance. A study assessing deer-vehicle collisions mitigation techniques reported that 42 of 43 states had addressed highway deer mortality (Romin and Bissonette 1996). The mitigation techniques used included; 1) hazing deer, 2) highway lighting, 3) lowered speed limits, 4) habitat alterations, 5) fencing, 6) modified overpasses and underpasses, 7) warning whistles, 8) public awareness programs, 9) warning signs, 10) and reflectors. Deer-crossing signs and public awareness programs were the most frequently used, but over 60% of the states did not know if these techniques were successful (Wood and Wolfe 1988, Romin and Bissonette 1996).

Romin and Bissonette (1996) identified fencing, intercept feeding (see below for definition), and overpasses or underpasses as the most promising techniques currently available for reducing deer-vehicle collisions. They also concluded that techniques to alter deer behavior and movement may be the most beneficial with regard to future application and research.

High deer-vehicle accident rates, such as those observed in some parts of Europe may not only pose a risk to motorists, but may have a significant impact on local deer populations (Putman 1997). In order to reduce deer-vehicle collisions, information regarding the interaction of deer and their environment may be necessary. Feldhamer et al. (1986) found that the existence of roadways did not impact the direction of travel of white-tailed deer (*Odocoileus virginianus*). Deer routinely cross secondary roads during their daily movements within their established home range (Putman 1997). Past studies have found that the sex ratio of road kills is often reflective of the sex ratio of the population (Feldhamer et al. 1986, Bruinderink and Hazebroek 1996). Feldhamer et al. (1986) found that individual male white-tailed deer crossed major and secondary roads more often than individual females. However, significantly more females than males were killed in deer-vehicle accidents, perhaps reflecting a female-biased sex ratio in the population. Daily and seasonal patterns of roadkills, with regard to life-history features of the species involved should be used in the development of methods for reducing animal-vehicle collisions (Bruinderink and Hazebroek 1996).

Carbaugh et al. (1975) concluded that deer-vehicle collisions were functions of the location of rights-of-way (ROW) in relation to deer feeding and bedding areas. White-tailed deer were observed more frequently along interstate highways from dusk until dawn than during daylight hours (Peek and Bellis 1969). Feldhamer et al. (1986) concluded that forage availability was the prime reason white-tailed deer entered the highway ROW in Pennsylvania.

## POSSIBLE CAUSES OF DEER VEHICLE COLLISIONS

Although thousands of deer-vehicle collisions occur each year, the possible causes of these accidents is not well understood. Very little research has been conducted on the effects of habitat on deer-vehicle collisions. The investigation of habitats adjacent to ROW has provided some information regarding possible factors associated with the location of deer-vehicle accidents. Bashore et al. (1985) found that across years, deer-vehicle collisions were aggregated around specific sites. They found that woodland-field interfaces were areas of higher deer-vehicle collisions. In areas with large amounts of woody cover (woody growth > 2 m) adjacent to the ROW, accident locations appear to be more randomly distributed (Bashore et al. 1985, Bellis and Graves 1971). Locations of deer-vehicle accidents appeared to be more concentrated in non-wooded areas in Pennsylvania (Bashore et al. 1985). However, in Michigan, Allen and McCullough (1976) reported that there did not appear to be any relationship between the location of deer-vehicle collisions and adjacent habitat types.

Factors other than habitat have been found to influence deer-vehicle collisions. In Pennsylvania, more deer-vehicle accidents occurred along 2-lane roads than along interstates (Bashore et al. 1985). Most deer-vehicle collisions occurred during early morning or 1-2 hr after sunset and appeared to be correlated to increased traffic volumes during those times (Allen and McCullough 1976).

Bashore et al. (1985) found that the probability of deer-vehicle accidents decreased as in relation to a host of other variables including: increases in the number of residences, commercial buildings, other buildings, speed limit, distances to woodland and fencing, and minimum visibility (either along or perpendicular to the roadway). They also found that road kills increased with increasing amounts of non-wooded area and in-line visibility (shortest distance at which an observer at the highway center line could no longer see a 2-m high board placed at edge of the pavement). They suggested that in non-wooded areas, deer crossings were more concentrated, and that in areas of high in-line visibility (i.e., long stretches of straight, level road), drivers increased their speed, which resulted in an increase in deer-vehicle collisions.

On a seasonal basis, deer behavior appears to be an important variable in deer-vehicle accidents (Allen and McCullough 1976). Higher numbers of deer-vehicle collisions were found to occurred in October-December in Pennsylvania and were believed to be associated with breeding activities and fall hunting seasons (Puglisi et al. 1974). Allen and McCullough (1976) also found that deer-vehicle collisions peaked in association with dispersal, breeding activity and the occurrence of hunting seasons. Spring dispersal and green-up of vegetation along a highway ROW may also be related to an increase in deer-vehicle collisions during this time (Puglisi et al. 1974).

## PROBLEMS WITH PAST RESEARCH

Numerous research studies have been conducted to evaluate the effectiveness of various methods aimed at reducing deer-vehicle collisions on our nation’s highways and of those in Europe. Unfortunately, the majority of those studies have not provided statistically valid results. In general, most studies have failed in one of two ways: 1) the studies have not included control areas to compare to treatment areas, or 2) the studies have lacked adequate replication of treatment and/or control areas. Both problems make the conclusions drawn from those studies statistically questionable and often invalid.

The reasons for the poor results derived from these studies are numerous, but often they are the result of a lack of monetary input sufficient to provide adequate replication. Furthermore, many studies exhibit poor initial statistical design in other ways. Studies that lack control areas do not provide means of comparison between treatment effects and natural, stochastic variation (e.g., population fluctuations, changes in traffic flow, habitat alteration, etc.). Also, studies that lack adequate replication often lack statistical power (i.e., the probability of incorrectly deciding that a treatment has no effect). For example, if a study is designed to test a hypothesis that treatment-A will reduce deer-vehicle collisions, the treatment must be compared to a similar area with no treatment applied (the "control treatment"). To conclude that the treatment has an effect it is necessary to show a substantial difference between areas with Treatment-A and the control areas. However, if there is a little difference between the Treatment-A and control areas, we cannot be confident that there is, indeed, no effect of Treatment-A, unless there have been many replications of both Treatment-A and the control treatment. It is, of course, necessary to establish treatment and control replicates in areas with similar accident rates. Studies without adequate replication (poor statistical power) commonly, and perhaps mistakenly, equate "no treatment effect" with little difference between the treatment and control areas. Unfortunately, the poor designs associated with past studies has resulted in state transportation agencies expending substantial amounts of monetary resources on repeating research or implementing deer-vehicle collision reduction methods that are not proven and may not actually reduce accident rates.

## METHODS USED FOR REDUCING DEER-VEHICLE COLLISIONS

Over the years, a variety of methods have been used in attempts to reduce deer-vehicle collisions. Unfortunately, the effectiveness of most methods is still questionable. Below is a detailed literature review of the methods most widely used to reduce deer-vehicle collisions.

### Fencing

Fencing has been used to reduce animal-vehicle collisions by state transportation agencies. However, fencing is often installed for reasons other than the reduction of animal-vehicle accidents and its effectiveness is limited. Romin and Bissonette (1996) found that only 10 states used fencing and overpasses or underpasses to reduce deer-vehicle collisions, but over 90% reported that they believed fencing was an effective method of reducing animal-vehicle accidents. Properly maintained "deer-proof" fences have been shown to be effective at preventing deer from accessing a highway ROW (Falk et al. 1978, Ludwig and Bremicker 1983, Feldhamer et al. 1986).

In Pennsylvania, fully repaired fencing decreased the probability that an area would be classified as a high deer-vehicle collision location (Bashore et al. 1985). Deer-vehicle accidents have been reduced by the use of big game fences in Colorado, Minnesota (Ludwig and Bremicker 1983), and Pennsylvania (Falk et al. 1978, Feldhamer et al. 1986). Ward (1982) reported a 90% reduction in deer-vehicle accidents along a 7.8 mi stretch of I-70 in Colorado after the construction of 8 ft high "deer-proof" fencing.

The proper height of "deer-proof" fencing is also questionable. Even a 2.2-m (7.2 ft) fence may be an effective barrier to deer (Falk et al. 1978). A 2.3-m (7.5 ft) high fence reduced mule deer (*O. hemionus*) use of a highway ROW by 42% in Utah (Lehnert and Bissonette 1997). In Pennsylvania, there was no statistical difference in the number of roadkills between sections of road with 2.7-m (8.9ft) and 2.2-m (7.2 ft) fencing (Feldhamer et al. 1986). However, the 2.7-m (8.9 ft) fence did reduce the number of deer groups in the ROW. Unfortunately, Bellis and Graves (1976) found that when food was abundant in the ROW and scarce in adjacent habitat, deer could easily jump 2.2-m (7.2 ft) fencing. Also, if a fencing option is selected for reducing deer-vehicle collisions, the use of angled extensions on fencing is not recommended because deer often become entangled on the fence (Putman 1997).

Feldhamer et al. (1986) concluded that deer rarely jumped 2.7-m (8.9 ft) fencing, but entered the ROW by going underneath the fence in areas of erosion and topographic contours. White-tailed deer were found to cross under gaps in fencing in excess of 23 cm (9 in; Falk et al. 1978).

Fencing must be inspected frequently and repaired to original condition to be successful at reducing collisions because animals quickly exploit breaks in the fence (Foster and Humphrey 1995). Apparently, deer continually test fencing, making a good maintenance program necessary (Ward 1982).

When considering fencing as a deterrent to deer movement, not only does height, quality, and maintenance of the fence need to be taken into account, but the length of the fence must also be considered. Reed et al. (1975) found that "deer-proof" fencing averaging 3.5 km in length did not prevent "end runs" by mule deer in Colorado. Reed et al. (1979) indicated that fencing should extend at least 0.8 km beyond areas with high deer populations. However, since white-tail deer do not exhibit migratory behavior like western mule deer, "end runs" are likely to be less of a problem in Iowa.

Unfortunately, no fence can prevent all deer from entering the ROW and, once trapped inside fencing, adequate exits may reduce the occurrence of deer-vehicle accidents (Feldhamer et al. 1986). The effectiveness of fencing is enhanced by providing alternate routes of passage to deer that are intent on crossing and by providing a means of exiting the ROW once deer become trapped (Putman 1997).

One-way gates (openings surrounded by outwardly pointing wires) that allow deer to leave the ROW once inside have been installed in some states. However, only 16.5% of mule deer (n = 243) recorded within the ROW between 2.3-m (7.5ft) high fence on a

Utah study, used one-way gates to exit the ROW, indicating that deer were reluctant to use the 1-way gates (Lehnert and Bissonette 1997). Lehnert and Bissonette (1997) suggested that earthen ramps may be a possible method for allowing deer to exit a fenced ROW.

Even though fencing, in association with other options (discussed below), may be the most effective method currently available for reducing deer-vehicle accidents, the cost of construction and maintenance may be prohibitive is some situations. Putman (1997) stated that game proof fencing may be extremely expensive and only warranted on major roads. Eight foot, game proof fencing along a 7.8 mile stretch of I-80 in Wyoming cost $240,000 to install in the early 1970's (Ward 1982). Reed et al. (1982) estimated that maintenance cost for fencing was approximately 1% of construction cost per year. An estimate derived from Iowa DOT historical bid data places the cost of materials and installation for 8-foot, chain-link fencing at approximately $42,000 per mile in Iowa (for one side of the road). Other types of fencing materials may be significantly less expensive than chain-link, but we know of no estimates currently available.

There is some deer-vehicle accident rate, below which, the benefit-cost ratio will not be favorable for fence construction, even if the fencing is 100% effective (Reed et al. 1982). Reed et al. (1982) recommended that 2.4-m (7.8ft) m fencing be constructed if the benefit-cost ratio exceeded 1.36:1. In Colorado, 2.4-m (7.8ft) fencing along 1 side of ROW, both sides of ROW, and both sides of ROW with an underpass, was found to be cost effective if 8, 16, or 24 deer-vehicle collisions occurred per year in a 1.61 km stretch of highway, respectively (Reed et al. 1982). McKnight (1969) concluded that even though fencing does not equate to total exclusion, in some situations, it accomplishes enough to be worth the cost of construction and maintenance.

Bashore et al. (1985) concluded that fencing was the cheapest and most effective method of reducing deer-vehicle collisions along short stretches of highway. Difficulties associated with “deer-proof” fencing that must be considered include inadequacies near ramps of interchanges and the need for continuous monitoring for holes and erosion gaps (Ward 1982). Feldhamer et al. (1986) indicated that efforts to reduce deer-vehicle collisions should focus on increasing the effectiveness of deer fences and reducing the attractiveness of the highway ROW for deer.

**Crosswalks**

In the past, crosswalks have been used in attempts to reduce deer-vehicle collisions. Crosswalks are usually used in conjunction with fencing to funnel deer to specific crossing locations. Deer crosswalks are dirt paths that run from 1-way gates in

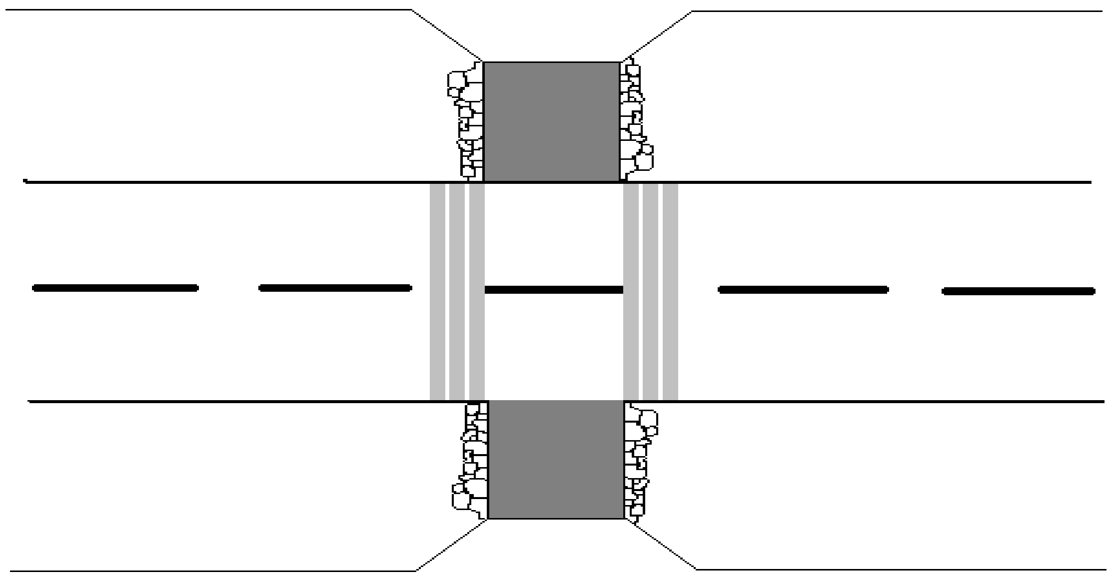


Fig 1. Graphic representation of deer crosswalk design used in Utah for allowing deer to cross a highway ROW at specific locations in "deer-proof" fencing.

highway fencing across dirt portions of the ROW. Paint is used to delineate crosswalkson the actual road surface. Stone river cobble, which is believed to deter deer from leaving the path is placed along both sides of the dirt path (Fig 1). Lehnert and Bissonette (1997) concluded that deer crosswalk systems reduced expected mortality by 42.3% and 36.8% on 4-lane and 2-lane highways, respectively. However, the reductions could not be statistically validated because there was no replication of the 2-lane and 4-lane highways evaluated, and the control section was not independent of the test sections.

The Utah study concluded that the crosswalk design may have increased the tendency of mule deer to walk on the road (Lehnert and Bissonette 1997). Most mortalities occurring in crosswalk treatment areas were the result of deer foraging within the median, ineffectiveness of 1-way ROW escape gates, and a lack of motorist response to warning signs (Lehnert and Bissonette 1997).

Complete elimination of deer-vehicle accidents is unlikely with the use of the crosswalk technique. However, they are a lower cost alternative to the construction of underpasses and overpasses. Lehnert and Bissonette (1997) estimated the cost of constructing deer crosswalks, not including 2.3-m (7.5ft) high fence construction and 1-

way gates, at $28,000 and $15,000 per structure on 4-lane and 2-lane highways, respectively.

**Underpasses and overpasses**

Other methods that allow deer to safely cross a highway ROW while reducing deer-vehicle collisions include the use of underpasses and overpasses. Wildlife underpasses have been shown to allow mountain goats (*Oreamnos americanus*; Singer and Doherty 1985) and Florida panthers (*Felis concolor coryi*; Foster and Humphrey 1995) to safely cross highways.

Deer have also been shown to use underpasses when they are available in Florida and Colorado (Reed et al. 1975, Ward 1982, Foster and Humphrey 1995). Deer were found to use underpass for travel and movement most during the early morning (Foster and Humphrey 1995). However, mule deer appeared to be reluctant to use the underpasses (Reed et al. 1975, Reed 1981*b*, Ward 1982).

Reed (1981*b*) found that 75% of mule deer that exited an underpass specifically constructed to aid deer movement in Colorado exhibited reluctant, wary, or frightened behavior. Deer behavior did not change at underpasses across a 10 yr period, which indicated that mule deer did not habituate to the small, fully enclosed underpass that was evaluated (Reed 1981*b*). However, migrating mule-deer were found to eventually incorporate underpasses into their migration patterns in Colorado (Reed et al. 1975). Ward (1982) also concluded that deer could learn to use underpasses over time. Reed (1981*b*) recommended the use of larger, open-bridge style underpasses that had less reluctant behavior from deer associated with them. Foster and Humphrey (1995) concluded that the use of wildlife underpasses without fencing would not solve animal vehicle collision problems, and fencing alone could fragment wildlife populations.

For methods that allow deer to cross a ROW to be effective, the existence and location of natural game paths should be taken into consideration during the planning phase (Bruinderink and Hazebroek 1996). Hanna (1992) reported that in Idaho, crossing structures that did not take into consideration traditional game trails failed to reduce deer-vehicle collisions. Further, they found that the addition of fencing to direct deer to the crossings did not help. Effective placement of wildlife underpasses is necessary and should take into consideration traditional deer trails and distances between underpasses (Foster and Humphrey 1995).

Visual characteristics of underpasses may influence their use by a wildlife species. Length, height, and width of underpasses influence their appearance to deer and are the primary stimuli affecting the acceptance of underpasses (Reed 1981*b*). Reed et al. (1975) recommended that underpasses be 4.27 m in height and width and of minimal length for mule-deer in Colorado, but Forster and Humphrey (1995) stated that underpasses of 2.1 m in height were sufficient for white-tailed deer in Florida.

Overpasses may be alternatives to underpasses for existing roadways (Putman 1997). Overpasses can be used effectively to reduce animal vehicle collisions when combined with fencing (Bruinderink and Hazebroek 1996). Overpasses with a minimum width of 30 m are necessary for successful use by animals and must be covered with dirt and grass (Putman 1997). However, the use of overpasses by animals seems to be less than that of underpasses.

The high cost of underpass construction may prevent their use in may areas (Lehnert and Bissonette 1997). Lehnert and Bissonette (1997) provided information estimating the cost of constructing underpasses on existing 4-lane and 2-lane roadways at $173,000 and $92,000, respectively.

Bruinderink and Hazebroek (1996) concluded that modification of existing roads was relatively expensive and the use of overpasses and underpasses should be included in the planning phase of new road development. Underpasses in new construction can be less costly because they can be made by simply enlarging structures that must be included in new development (Putman 1997). If hydrological features are taken into account, underpasses can be constructed more economically than overpasses for use in reducing deer-vehicle collisions (Reed et al. 1975, Reed 1981*b*).

Modified bridges that have plenty of room for deer to cross, coupled with 2.7-m (8.9ft) high fences, may guide deer and keep them from accessing the ROW in high mortality areas associated with river crossings. This may be an economically efficient means of directing deer movement. However, bridges must be constructed with this purpose in mind.

Underpasses and overpasses that are considered for use in reducing deer-vehicle accidents must be given special consideration. Both overpasses and underpasses require an adjustment period for deer to become accustomed to them (Putman 1997). The utilization of underpasses and overpasses can be increased by placing them in areas of cover on both sides of the ROW and using fencing to funnel deer toward their openings (Putman 1997). Also, Bruinderink and Hazebroek (1996) recommended that underpasses and overpasses be given refuge status so deer do not suffer adverse consequences while crossing a ROW.

**Reflectors**

In the past, reflectors and specialized mirrors have been used as alternatives to fencing to reduce deer-vehicle collisions. Unlike fencing, reflectors, in theory, provide a "barrier" only when vehicles are present, thus allowing normal movement and dispersal (Putman 1997).

Swareflex® (D. Swarovski Corp., Austria) reflectors are based on the assumption that deer can distinguish red as a color, but there is very little evidence supporting this claim (Putman 1997). An underlying assumption of Swareflex reflectors is that deer are attentive to the reflected red light as vehicles approach and remain motionless (Shafer and Penland 1985). However, Zacks (1985) found no evidence that red-light deterred deer from moving toward the light. He also concluded that there was no evidence of deer being frightened by red light reflected from Swareflex reflectors.

Some researchers (Zacks 1986, Waring et al. 1991) even question the underlying assumption that deer instinctively avoid, or alter their behavior in response to the red light produced by the illuminated reflectors" (Lehnert and Bissonette 1997). In a study using penned white-tailed deer, no evidence was found that Swareflex reflectors prevented deer from using an area (Zacks 1986). Unfortunately, in the Zacks (1986) study, a stationary light source was used and would not have produced the prism effect from the reflector believed to contribute to the freezing behavior in deer (J. Strieter, pers. comm). Zacks (1986) suggested that reflectors may influence motorist behavior rather that deer behavior. However, with proper installation, motorists should not be aware of the reflectors (J. Strieter, pers. comm).

Tests regarding the effectiveness of Swareflex reflectors have yielded mixed results (Gladfelter 1984, Schafer and Penland 1985, Reeve and Anderson 1993). Most tests have compared before- and after-installation accident rates. These studies have not allowed statistically valid evaluation of the effectiveness of the reflectors at reducing deer-vehicle accidents (Schafer and Penland 1985), because they do not account for changes in deer populations, traffic levels, or other environmental trends.

Schafer and Penland (1985) used a covered and uncovered paired t-test design in Washington to evaluate the effectiveness of Swareflex reflectors at reducing deer-vehicle accidents. They concluded that the reflectors significantly reduced the number of deer killed by vehicles. However, Swareflex reflectors were found to not reduce mule-deer vehicle collisions in studies conducted by Reeve and Anderson (1993), Ford and Villa (1993), and Gilbert (1982). In Wyoming, Reeve and Anderson (1993) also used a covered-uncovered design to evaluated the effectiveness of Swareflex reflectors. They reported that a *greater* than expected number of deer was killed on a test section of US Highway 30 in Wyoming when Swareflex reflectors were uncovered and operating ($\chi^2$ = 40.88, 2 df, $P < 0.001$). They concluded that Swareflex reflectors had no effect on mule deer-vehicle collisions in Wyoming (Reeve and Anderson 1993). The Reeve and Anderson (1993) study was conducted over 3 yrs. Waring et al. (1991) also concluded that Swareflex reflectors did not reduce deer-vehicle accidents in Illinois even though the deer population declined during their study.

A common problem with conclusions drawn from reflector studies is their small sample sizes (Romin and Bissonette 1996) and poor statistical designs. In Iowa, Gladfelter (1984) suggested that Swareflex reflectors reduced the number of deer-vehicle collisions. However, so few deer were killed in the Iowa (Gladfelter 1984) and Washington studies (Schafer and Penland 1985) that the apparent reduction in deer-vehicle accidents after Swareflex reflector installation may have been due to random chance rather than an effect of the reflectors (Reeve and Anderson 1993). Waring et al. (1991) recommended that "highway departments and refuges not rely on such reflectors to reduce deer-vehicle collisions."

Deer behavior during road crossings did not appear to be influenced by the presence of Swareflex reflectors (Waring et al. 1991). In areas of high traffic volume, deer may habituate to reflectors more quickly and reduce their value (Putman 1997). Waring et al. (1991) concluded that if deer reacted to reflectors, the reactions diminished quickly. Most tests evaluating reflectors have only been conducted for 2 years. Schafer and Penland (1985) recommended that long-term testing was warranted to evaluate the possibility of deer becoming desensitized to the reflectors. Indeed, Ujvàri et al. (1998) found that, over a couple of weeks, fallow deer in Denmark habituated to WEGU reflectors which are similar to the Swareflex reflector.

Installation of Swareflex reflectors costs between $8-10,000/mile (T. Crouch, Iowa DOT traffic engineer *in* Anonymous 1998). After a 3 year study in Wyoming, Reeve and Anderson (1993) reported that only 61% of Swareflex reflectors were in good shape. Gladfelter (1984) reported that a structural design problem caused the reflectors to break off their posts after several months of use. However, since this time, Swareflex reflectors have been redesigned to eliminate some of the problems observed in the Wyoming and Iowa studies.

Unfortunately, "to date, no objective tests have been published on the use of reflectors" (Putman 1997). Currently, red and blue-green Swareflex reflectors are being tested in Illinois (J. Strieter, pers. comm.) to evaluate a suggestion that deer may be sensitive to light in the ultra-violet end of the visible spectrum (Putman 1997). Michigan is also designing research using neural network analysis to evaluate the effectiveness of reflectors at reducing deer-vehicle collisions (Strieter and Randolph, pers. comm.). In the Michigan study's current design, there will be no control areas for comparison to treatment areas to statistically validate treatment effects. On minor roads, where delaying or directing crossing, not eliminating it, is the goal, reflectors may be an appropriate and economical solution (Putman 1997), if they can be statistically proven to reduce deer-vehicle collisions.

## MISCELLANEOUS REDUCTION METHODS

### Wildlife warning whistles

Wildlife warning whistles, attached to individual cars, have also been used in attempts to reduce deer-vehicle collisions. Wildlife warning whistles operate at frequencies of 16-20 k Hz and are suppose to warn animals of approaching vehicles and reduce collisions (Romin and Dalton 1992). Unfortunately, there does not appear to be any research that has demonstrated that deer are frightened by a particular frequency or decibel level of sound (Romin and Dalton 1992). In a well designed study in Utah, two popular brands of ultrasonic whistles were found to have no effect on the behavior of free-ranging mule deer (Romin and Dalton 1992). If wildlife warning whistles work at all, they may not be alarming to deer or they may not be loud enough to be heard above engine noise associated with moving vehicles (Romin and Dalton 1992).

### Highway lighting

In Colorado, 92% of reported deer-vehicle collisions occurred from sunset to sunrise (Reed 1981*a*). Reed (1981*a*) hypothesized that an increase in illumination of roadways may enhance motorists' night vision and reduce deer-vehicle collisions. Highway lighting did not affect motorist behavior or deer crossings-per-accident ratios (Reed 1981*a*). Also, highway lighting did not affect the location of deer crossings or their behavior (Reed 1981*a*). Reed (1981*a*) concluded that increased highway lighting was not effective at reducing deer-vehicle accidents.

### Right-of-way plantings and intercept feeding

In areas with large amounts of timber, a highway ROW may provide deer with attractive areas to forage (Feldhamer et al. 1986). To reduce the attractiveness of a ROW to ungulates, unpalatable plant species should be planted and mast producing trees should be avoided (Bruinderink and Hazebroek 1996).

Providing deer with areas other than the ROW to forage has also been shown to reduce deer vehicle collisions. Wood and Wolf (1988) concluded that intercept feeding (providing deer food sources between bedding areas and highway ROWs) may have reduced deer-vehicle collisions by 50% in Utah. However, intercept feeding was not recommended for long term deer-vehicle accident reduction, but only for short-term reductions in areas of high concentrations of deer (Wood and Wolfe 1988).

**Salt alternatives**

In some areas, salt may attract deer to the ROW. Salt may accumulate on the side of roadways during spring and attract deer in areas where there are few natural salt sources (Bruinderink and Hazebroek 1996). Feldhamer et al. (1986) suggested that deicers without salt could be used in areas of high deer-vehicle accidents to reduce the attractiveness of the ROW. Finnish roe deer biologists have recommended that CaMg-acetate be used to deice roads instead of NaCl (Bruinderink and Hazebroek 1996).

**Warning signs**

Signs that warn motorist of high deer-crossing probabilities are the most common approach to reducing deer-vehicle collisions (Putman 1997). Romin and Bissonette (1996) suggested that deer crossing signs may be effective if drivers' would reduce their vehicle speed. However, deer crossing signs may not be useful in the long term because warning signs are common for long stretches of road and drivers become complacent unless the warning on the sign is reinforced by actual experience (Putman 1997).

Lighted, animated deer-crossing warning signs were evaluated in Colorado. Animated deer crossing signs reduced vehicle speed by 3 mph (Pojar et al. 1975). Mule deer-vehicle accidents were not affected by signs (Pojar et al. 1975). Pojar et al. (1975) concluded that motorist observed the animated signs, but their reduction in speed was not enough to affect the crossing per kill ratio.

Pojar et al. (1975) indicated that when motorists were shown that a danger existed, they exhibited a greater response than if they were merely warned of danger by a deer-crossing sign. They evaluated this assumption by placing three dead deer carcasses on the shoulder of the ROW, next to a deer-crossing sign. Vehicle speed was reduced by 7.85 mph after passing the carcasses. The test was quickly discontinued for liability reasons, but the idea that the association of danger with a warning sign produces a pronounced response appears valid.

**Deer mirrors**

Deer mirrors (round conventional mirrors which directly reflect headlights off the highway and into the surrounding ROW) have also be evaluated as a deer-vehicle reduction method. Queal (1967) and Beauchamp (1970) found that deer mirrors reduced deer-vehicle collisions during the first year after installation. However, accident rates returned to pre-treatment levels during the second year of study. This result indicates that deer became accustom to the reflected light and began to ignore it over time.

**Chemical repellants**

Chemical repellants and noise deterrents have been used in Europe to reduce deer-vehicle accident rates. Chemical fences have been used in Germany to reduce deer-vehicle collisions, but have not been adequately tested (Putman 1997). Chemical fences are sprayed along roadways and are in the form of chemical repellent compounds micro-encapsulated in organic foam that breaks down during daylight, releasing the compound (Putman 1997).

**Deer herd reduction**

Controlling local deer levels has also been attempted to reduce accident rates. Allen and McCullough (1976) suggested that controlling deer population numbers through harvest may be an effective method for reducing deer-vehicle accidents. Michigan and Illinois have used hunting in an attempt to reduce local deer populations and decrease deer-vehicle collisions (Romin and Bissonette 1996). However, Waring et al. (1991) found that deer-vehicle collisions did not decline on their study area even though the deer population decreased. In Iowa, a decrease in the white-tailed deer herd in the late 1980s resulted in a corresponding reduction in the number of deer-vehicle collision (W. Suchy, Iowa DNR deer research biologist, pers. comm.).

**Speed limits, hazing, and public awareness campaigns**

Strongly enforced lower speed limits may reduce deer-vehicle collisions (Romin and Bissonette 1996). Unfortunately, no scientific study has been done to evaluate the effectiveness of hazing, public awareness campaigns, or reduced speed limits (Romin and Bissonette 1996).

**Possible vehicle modifications and devices**

Modification of vehicles may reduce animal-vehicle collisions. In Europe, vehicles are equipped with headlights that may reduce the tendency for deer to “freeze” in highway ROWs when startled by approaching traffic (regulations prevent the lower-glare European-style headlights in the United States). Also, windshield wipers on European vehicles are required to clear a larger visual area faster than wipers on U.S. automobiles which may reduce animal-vehicle collisions by increasing driver reaction time during inclement weather.

Technological devices to reduce deer-vehicle accidents are also being developed by some automobile manufacturers. General Motors is developing an infra-red detection system to be offered on some vehicles in 2000. The infra-red detection system would be mounted on the grill of the vehicle and detect long-range infra-red signals (from 8-14 microns). The infra-red signals would be converted into a video signal and projected to the driver via a heads-up video display projected on the lower portion of the drivers windshield. Unfortunately, this device has not yet been made available to the public and its effectiveness has not been evaluated.

## POSSIBLE METHODS OF REDUCTION

In addition to the methods that have been previously used in attempts to reduce deer-vehicle collision, other possible methods may be worthy of consideration. First, we suggest that accidents might be reduced with signs indicating the number of deer-vehicle collisions within the next mile during the previous year may provide motorists with a danger association not provided by normal deer-crossing warning signs.

Alternatively, for secondary roads, Bruinderink and Hazebroek (1996) recommended the "application of intermittently lighted warning signs, triggered if possible by the ungulates." Fencing that directs deer to specific crossings in conjunction with warning signs that flash only when animals are in the ROW would provide motorists with a direct association of danger, possibly resulting in a reduction of deer-vehicle collisions.

An exhaustive literature review provided no evidence that devices that are triggered by animal movement or body heat have been scientifically evaluated as deer-vehicle reduction methods. Current technologies that detect both movement and body heat are common in the private sector for use in home security, outdoor lighting, and hunting. However, a demand for the application of this technology to the reduction of deer-vehicle accidents has not been made until recently (B. Goodson, Goodson and Associates Inc., pers. comm.). Therefore, the technology's effectiveness and durability have not been evaluated.

Personal contact with private corporations and individuals has provided base-line information on the feasibility, durability, and estimates of cost of this technology. However, this information should be considered general, and the estimates of range and cost should be considered hypothetical since this technology has never be evaluated for use in reducing deer-vehicle collisions, nor is it currently being mass produced in configurations suitable for this use.

In our opinion, motion detector technology is probably less feasible than infra-red technology because of changing and moving vegetation along a highway ROW. Tall, moving vegetation may trigger motion detectors, so their sensitivity would necessarily have to be reduced, or areas would have to be mowed frequently to reduce the possibility that warnings would be associated with non-animal events.

Infra-red technology may provide a reliable method for detecting deer and reducing deer-vehicle collisions. Two types of infra-red detectors exist; passive and active. Passive infra-red detectors are probably more reliable and have a lower cost associated with them than do active detectors. However, passive infra-red detectors may provide some false positive readings, triggering warning devices when animals are not in the ROW. False positive readings were estimated to be at or below 1% of responses (B. Goodson, owner Goodson and Associates, Inc. pers. comm.). Infra-red detectors can be constructed to detect changes in temperature of $\leq 1°$ C and run on 4 c-cell batteries for up to 1 yr. Goodson estimated that detectors can be reliable up to 100 feet. The width of the detector's area of sensitivity can also be set to eliminate the detector from being triggered by motor vehicles.

Trailmaster, Inc. (subsidiary of Goodson and Associates, Inc.) estimated that prototype infra-red detectors for use in triggering warning signs could be constructed for approximately $180/unit. If flashing warning signs and solar panels to power them are included, the estimated cost would be $1000-1200/unit. Unfortunately, infra-red sensors loose their sensitivity over time, but the units can be constructed so that just the sensors can be easily changed. This would probably need to be done once every two years. The sensor could probably be changed on site, or returned to the manufacture. The cost of new sensors was estimated at $7-10/unit (B. Goodson, pers. comm.). If vandalism of detectors is found to be a problem, they can be made “bullet-proof” for an extra charge (the window that the sensor “sees” through must remain relatively thin, increasing the cost substantially).

A local entrepreneur (D. Hennington) has also been contacted with regard to the specifics of an infra-red detector that he has developed for use in animal-vehicle collision reduction. His unit is also untested, but has an estimated cost, in quantity, of $50/unit. The unit is estimated to have a reliable range of 60 ft and an adjustable width. The sensitivity of his unit, with regards to sensing temperature changes, is unknown.

## CONCLUSIONS

Americans are not homogenous in their feelings and attitudes regarding animals (Kellert 1984). Consideration of the various attitudes and demands of the public is necessary when addressing deer-vehicle reduction methods.

An individuals perception's of the probability of deer-vehicle collisions may influence their attitudes regarding deer populations and various management objectives (Stout et al. 1993). The positive value associated with deer include recreational value for both hunters and sightseers, while negative values can include deer-vehicle collisions, Lyme disease, and damage to agricultural crops (Conover 1997*a*). In a study conducted by Conover (1997*b*), only 15% of metropolitan residents in the United States reported that they wanted reduced numbers of deer in their neighborhoods. Even in Iowa, responses to deer management decisions are varied. In a survey conducted in central Iowa in 1998, over 50% of respondents felt that deer populations were not too large and nearly 50% reported neutral feelings toward deer-interactions (Suchy 1998).

"Cost-benefit analysis has made it clear that substantial investment in accident prevention measures is amply justified on purely economic grounds" (Putman 1997). Hansen (1983) estimated that a device that prevented 1 deer-vehicle collision/yr, with a useful life of 5 yrs. could cost $3,020 in 1978 and still be economical.

Properly maintained fencing is the only sure way to dramatically reduce deer-vehicle collisions on main roads (Falk et al. 1978, Putman 1997). On high-speed, high-volume roads, a combination of wildlife passages and fencing appears to be the most reliable method for reducing animal-vehicle collisions (Bruinderink and Hazebroek 1996). Furthermore, to determine that passage structures are, indeed, effective, a monitoring system that uses infra-red detection equipment is necessary (Bruinderink and Hazebroek 1996). Also, since drivers are ultimately responsible for the consequences of animal-vehicle collisions, public awareness campaigns and driver awareness programs should be part of future research efforts (Pojar et al. 1975, Bruinderink and Hazebroek 1996).

## PROGRESS ON CURRENT RESEARCH OF LANDSCAPE EFFECTS ASSOCIATED WITH DEER-VEHICLE COLLISION SITES AND FUTURE RESEARCH PLANS

We are currently developing a model that predicts the probability of deer-vehicle accidents given the proper habitat information (e.g., habitat types, amounts, and spatial relationships to other habitat types) as well as necessary inputs for traffic flow, deer population estimates, and various other variables that may increase the models predictive abilities (e.g., distance to nearest river, distance to nearest town, seasonality, etc.). Once the model is developed, it will be applied to areas within the state of Iowa that were not used in creating the model. These areas will be used to validate the model and determine its predictive capabilities.

Over 66% of the mile posts in the state of Iowa have had at least one deer-vehicle collision associated with them since 1990. Our model should be able to distinguish between areas of high deer accident rates and areas of few deer accident rates. We are most interested in areas of high accident rate classification, since these are the areas that will benefit the most from the application of methods to reduce deer-vehicle collision. When and if the model proves valid, we will be able to pinpoint those areas across the state that have the highest probability of deer-vehicle accidents occurring. If the study is continued in the future on a large scale to evaluate possible methods for reducing deer-vehicle collision, the model will allow us to select areas across the state that have similar statistical probabilities for vehicle accidents involving deer. The ability to select areas that have similar probabilities is essential to our ability to draw accurate conclusions from any study designed to evaluate possible reduction methods. Also, in the future, we may be able to predict areas of high deer-vehicle collision rates prior to the construction of new highways or modification of existing highways, so the application of methods to reduce animal vehicle collisions can be included during the planning phase.

Currently, we are developing a program for use with a geographic information system (GIS), to select 1-square mile areas around selected mileposts throughout the state for use in developing a model to predict deer-vehicle collision rates. Databases have been created containing variables (other than landscape measures) considered important in predicting deer-vehicle collisions (e.g., number of deer hit since 1990 at each mile post within the state, associated traffic flow information, distance to nearest town, distance to nearest town with population greater than 2000, number of streams and bridges within ½ mile of each milepost, etc.). Arrangements have been made to acquire deer population estimates and harvest records from the Iowa Department of Natural Resources (IDNR). At present, we are waiting for the state-wide landscape cover map of Iowa that is being created by the IDNR in Iowa City. We hope to have that information by the mid- to late August. Upon receipt of this data layer, we will proceed with model development.

**LITERATURE CITED**

Allen, R. E., and D. R. McCullough. 1976. Deer-car accidents in southern Michigan. Journal of Wildlife Management 40:317-325.

Anonymous. 1998. Fence of light stops deer. Technology News 2:7.

Bashore, T. L., W. M. Tzilkowski, and E. D. Bellis. 1985. Analysis of deer-vehicle collision sites in Pennsylvania. Journal of Wildlife Management 49:769-774.

Bruinderink, G. W. T. A., and E. Hazebroek. 1996. Ungulate traffic collisions in Europe. Conservation Biology 10:1059-1067.

Beauchamp. D. E. 1970. Deer mirror evaluation. California Department of Fish and Game. 8 pp.

Bellis, , E. D., and H. B. Graves. 1971. Deer mortality on a Pennsylvania interstate. Journal of Wildlife Management 35:232-237.

Carbaugh, B. , and J. P. Vaughan, E. D. Bellis, and H. B. Graves. 1975. Distribution and activity of white-tailed deer along an interstate highway. Journal of Wildlife Management 39:570-581.

Case, R. M. 1978. Interstate highway road killed animals: a data source for biologists. Wildlife Society Bulletin 6:8-13.

Conover, M. R. 1997*a*. Monetary and intangible valuation of deer in the United States. Wildlife Society Bulletin 25:298-305.

-----. 1997*b*. Wildlife management by metropolitan residents inthe United States: practices, perceptions, costs, and values. Wildlife Society Bulletin 25:306-311.

-----. 1994. Perceptions of grass-roots leaders of the agricultural community about wildlife damage on their farms and ranches. Wildlife Society bulletin 22:94-100.

-----, W. C. Pitt, K. K. Kessler, T. J. DuBow, and W. A. Sanborn. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. Wildlife Society Bulletin 23:407-414.

Falk, N. W., H. B. Graves, and E. D. Bellis. 1978. Highway right-of-way fences as deer deterrents. Journal of Wildlife Management. 42:646-650.

Feldhamer, G. A., J. E. Gates, D. M. Harman, A. J. Loranger, and K. R. Dixon. 1986. Effects of interstate highway fencing on white-tailed deer activity. Journal of Wildlife Management 50:497-503.

Ford, S. G., and S. L. Villa. 1993. Reflector use and the effect they have on the number of mule deer killed on California highways. Report FHWA-CA-PD94-01.

Foster, M. L., and S. R. Humphrey. 1995. Use of underpasses by Florida panthers and other wildlife. Wildlife Society Bulletin 23:95-100.

Gilbert, J. R. 1982. Evaluation of deer mirrors for reducing deer-vehicle collisions. United States Federal Highway Administration report FHWA-RD-82-061. 16 pp.

Gladfelter, L. 1984. Effect of wildlife highway warning reflectors on deer-vehicle accidents. Iowa Highway Research Board Project HR-210. Iowa Department of Transportation. 11pp.

Hanna, P. 1982. The impact of Interstate Highway 84 on the Sublette-Black Pine migratiory deer population. A 12-year summary, with recommendations for mitigation of identifiable adverse impacts. Final report, Project W-160, Idaho Department of Fish and Game. 97 pp.

Hansen, C. S. 1983. Costs of deer-vehicle accidents in Michigan. Wildlife Society Bulletin 11:161-164.

Kellert, S. R. 1984. Urban american perceptions of animals and the natural environment. Urban Ecology 8:209-228.

Knight, J. E., E. J. Swensson, and H. Sherwood. 1997. Elk use of modified fence-crossing designs. Wildlife Society Bulletin 25:819-822.

Lehnert, M. E., and J. A. Bissonette. 1997. Effectiveness of highway crosswalk structures at reducing deer-vehicle collisions. Wildlife Society Bulletin 25:809-818.

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

Mackie, R. J. 1981. Interspecific relationships. Pages 487-507 *in* O.C. Wallmo, ed. Mule and black-tailed deer of North America. University of Nebraska Press, Lincoln.

McKnight, T. L. 1969. Barrier fencing for vermin control in Australia. Geographical Review 59:330-347.

Nationwide Insurance. 1993. Deer and moose collisions: no laughing matter. Nationwide Summer 1993, Portland, Oregon. 3 pp.

Peek, F. W., and E. D. Bellis. 1969. Deer movements and behavior along an interstate highway. Highway Research News 36:36-42.

Pojar, T. M., R. A. Prosence, D. F. Reed, and R. H. Woodward. 1975. Effectiveness of a lighted, animated deer crossing sign. Journal of Wildlife Management 39:87-91.

Puglisi, M. J., J. S. Lindzey, and E. D. Bellis. 1974. Factors associated with highway mortality of white-tailed deer. Journal of Wildlife Management 38:799-807.

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

Queal, L. M. 1967. Effectiveness of roadside mirrors in controlling deer-car accidents. Michigan Department of Conservation, Research Division Report 103. 7 pp.

Reed, D. F., T. D. I. Beck, and T. N. Woodard. 1982. Methods of reducing deer-vehicle accidents: benefit-cost analysis. Wildlife Society Bulletin 10:349-354.

-----. 1981*a*. Effectiveness of highway lighting in reducing deer-vehicle collisions. Journal of wildlife management 45:721-726.

-----. 1981*b*. Mule deer behavior at a highway underpass exit. Journal of Wildlife Management 45:542-543.

-----, T. N. Woodward, and T. D. I. Beck. 1979. Regional deer-vehicle accident research. U. S. Department of Transportation Federal Highway Administration Report No. FHWA-RD-79-11. National Technical Information Service, Springfield, Virginia.. 61 pp.

-----, T. N. Woodward, and T. M. Pojar. 1975. Behavioral response of mule deer to a highway underpass. Journal of Wildlife Management 39:361-367.

Reeve, A. F., and S. H. Anderson. 1993. Ineffectiveness of Swareflex reflectors at reducing deer-vehicle collisions. Wildlife Society Bulletin 21:127-132.

Reilly, R. E., and H. E. Green. 1974. Deer mortality on a Michigan interstate highway. Journal of Wildlife Management 38:16-19.

Romin, L. A., and J. A. Bissonette. 1996. Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. Wildlife Society Bulletin 24:276-283.

-----, and L. B. Dalton. 1992. Lack of response by mule deer to wildlife warning whistles. Wildlife Society Bulletin 20:382-384.

Shafer, J. A., and S. T. Penland. 1985. Effectiveness of Swareflex reflectors in reducing deer-vehicle accidents. Journal of Wildlife Management 49:774-776.

Singer, F. J., and J. L. Doherty. 1985. Managing mountain goats at a highway crossing. Wildlife Society Bulletin 13:469-477.

Stout, R. J., R. C. Stedman, D. J. Decker, and B. A. Knuth. 1993. Perceptions of risk from deer-related vehicle accidents: implications for public preferences for deer herd size. Wildlife Society Bulletin 21:237-249.

Suchy, W. J. 1998. Simpson Poll: attitudes about deer and deer management options. Iowa Department of Natural Resources In House Report. 6 pp.

Ujvàri, M., H. J. Baagøe, and A. B. Masen. 1998. Effectiveness of wildlife warning reflectors in reducing deer-vehicle collisions: a behavioral study. Journal of Wildlife Management 62: 1094-1099.

U.S. Department of Interior, Fish and Wildlife Service and U.S. Department of Commerce, Bureau of the Census. 1996. National survey of fishing, hunting, and wildlife-associated recreation.

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

Waring, G. H., J. L. Griffs, and M. E. Vaughn. 1991. White-tailed deer roadside behavior, wildlife warning reflectors, and highway mortality. Applied Animal Behaviourial Science 29:215-223.

Williamson, L. 1980. Reflectors reduce deer-auto collisions. Outdoor News Bulletin 34:2.

Wood, P., and M. L. Wolfe. 1988. Intercept feeding as a means of reducing deer-vehicle collisions. Wildlife Society Bulletin 16:376-380.

Zacks, J. L. 1985. An investigation of Swareflex wildlife warning reflectors. Federal Highway Administration Report FHWA-MI-RD-85-04, Washington, D.C. 53 pp.

-----. 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.