

LITERATURE SUMMARY
ASSESSING METHODS
FOR REDUCING DEER-VEHICLE ACCIDENTS

Prepared by Mark Watson and Jon Klingel

15 May 2000

Summary :

We provide a review and summary of the literature assessing mitigation strategies and techniques for reducing deer-vehicle accidents (DVA). Much of the information, including criticisms of certain techniques and recommendations, are summarized in two reviews of the literature by Danielson and Hubbard (1998), and Reed (1995). These reviews considered the following methods for reducing DVA: 1) fencing; 2) crosswalks; 3) underpasses; 4) overpasses; 5) wildlife reflectors; 6) wildlife warning whistles; 7) highway lighting; 8) vegetation manipulations, intercept feeding and salt alternatives; 9) warning signs, speed limit reduction and driver education; 10) chemical repellants; 11) deer herd reduction; and 12) possible vehicle modifications and devices.

Reed (1995) found that a 2.44 meter (eight foot) fence was effective if constructed properly, adequately maintained, and used in conjunction with underpasses or overpasses and one-way gates. Well-maintained fencing is apparently the only certain method for significantly reducing

DVA on primary roads (Falk et al. 1978, Putnam 1997). Reed (1995) gave fencing a 78.5% effectiveness rating at reducing DVA (see Reed 1995, Table 2).

Underpasses are effective if used with fencing and designed and constructed with an "openness factor" (underpass height times the width, divided by the length) that does not preclude cervid use (Reed 1995). Overpasses are effective if used in conjunction with fencing and designed with a "bridge effect factor" (width times the square root of the height divided by the length) that does not preclude cervid use (Reed 1995). For high traffic-volume roads, a combination of fencing and wildlife underpasses or overpasses appears to be the most successful strategy for reducing DVA (Bruinderink and Hazebroek 1996).

Romin and Bisonnette (1996) identified methods that alter deer behavior and movements, such as fencing, intercept feeding and overpasses or underpasses, as the most promising techniques currently available, and recommended additional research along those lines.

Properly designed experimental studies investigating the effectiveness of driver education, hunting, speed reduction and ultrasonics at reducing DVA are lacking (Reed 1995). Highway lighting and increased-visibility warning signs have not been shown to be effective at modifying driver behavior and reducing DVA (Reed 1995). Studies of the effects of vegetation manipulation along roadways are inadequate (Reed 1995). Studies results from wildlife reflector tests have produced conflicting results, but in general, these studies have not been designed with adequate controls or sample sizes to provide statistically significant results (Reed 1995). Reed (1995) recommends that additional research be conducted to determine the effectiveness of these methods.

Danielson and Hubbard (1998) discussed the status of current research for future technologies for reducing DVA, and find promise in the development of infra-red sensing devices triggered by animal movements that relay signals to warning signs at deer crossing areas.

Putnam (1997) strongly suggested that the determination of an appropriate method for reducing DVA should be based on as complete an understanding of the accident patterns as possible, including wildlife and traffic patterns and processes. Bruinderink and Hazebroek (1996) stated that daily and seasonal patterns of accidents and life-history attributes and population dynamics of target animals should be used to develop strategies for reducing DVA. DVA mitigation applications could be site or species specific (Romin and Bissonette 1996).

Background :

DVA have increased significantly in North America since 1980 (Romin and Bissonette 1996). Williamson (1980) reported that 200,000 deer were killed from DVA in the U.S. in 1980. Romin and Bissonette (1996) estimated that more than 538,000 deer were killed in the U.S. by vehicles in 1991. This estimate must be considered conservative since numerous DVA are not reported, and included DVA data from only 36 states (Lehnert and Bissonette 1997). Conover et al. (1995) reports that an estimated 1.5 million DVA occur annually in the U.S., and only 50% of DVA are reported or documented (Decker et al. 1990, Romin 1994). Conover et al. (1995) estimated that DVA in the U.S. annually result in 211 human fatalities, 29,000 human injuries, and more than \$1 billion in property damage. Danielson and Hubbard (1998) estimate combined annual economic loss in the U.S. from DVA at more than two billion dollars from human and animal casualties and property damage.

Romin and Bissonette (1996) found that most states in the U.S. have implemented techniques to reduce DVA, but very little evaluation of performance had been conducted by implementing agencies. They conducted a study that found that 42 of 43 states had implemented DVA mitigation techniques (see Romin and Bissonette 1996, Table 2). Of 10 different mitigation techniques implemented (similar to methods evaluated in Reed 1995), deer crossing signs and public awareness programs were the most frequently used; however, over 60% of these states did not know if the techniques were successful.

Putnam (1997) found that techniques implemented to reduce DVA are often arbitrary and without follow-up monitoring to determine effectiveness, therefore cost-to-benefit ratios are poorly understood. Romin and Bissonette (1996) found that peer-reviewed literature on DVA reduction methods is limited and found primarily in state agency publications. They found few rigorous evaluations of method effectiveness, and that most evaluations that were conducted were based on opinion.

Problems with past research

Danielson and Hubbard (1998) identify two major deficiencies that have precluded the majority of DVA mitigation studies from providing statistically valid results: 1) the lack of control areas to compare to treatment areas; and 2) the lack of adequate replication of treatment and control areas. Studies without controls lack the ability to compare treatment results with uncontrolled variables such as yearly weather variability, population and traffic fluctuations, and habitat changes. Studies without adequate replication may not provide the statistical power to determine if a treatment actually works.

Methods used for reducing deer-vehicle accidents

1. Fencing

Fences are used to mitigate collisions by either precluding animals from entering highways, or diverting animals to crossing structures such as underpasses or overpasses (Reed 1995). Several studies (Free and Severinghaus undated; Lavsund and Sandegren 1991; Reed et al. 1979; Ward et al. 1979; and Ward 1982) have shown fencing (primarily 2.44 meter, 8-foot fence) to be effective at reducing DVA.

Romin and Bissonette (1996) reported that 10 states used a combination of fencing, overpasses or underpasses to mitigate DVA, but more than 90% of these states believed fencing was effective at reducing DVA (see Romin and Bissonette 1996, Table 3). Danielson and Hubbard (1998) reported that reduction of DVA from the installation of fencing has been documented in Colorado, Minnesota (Ludwig and Bremicker 1983), and Pennsylvania (Falk et al. 1978, Feldhamer et al. 1986). Ward (1982) documented a 90% DVA reduction along a 7.8 mile segment of I-70 in Colorado where an 8-foot deer fence was installed.

According to Reed (1995), to ensure approximately 80-90% collision reduction after installation, 8-foot fences must be resistant to deer passage by ensuring adequate basal closure during construction and providing constant maintenance. Danielson and Hubbard (1998) also emphasize that fencing must be maintained by regularly inspection and repair to preclude deer entry onto roads. Ward (1982) reported that mule deer along Interstate 80 in Wyoming continually tested fencing, requiring a rigorous maintenance program.

Reed (1995) stated that 8-foot fences must extend approximately 0.8 km (0.5 mi.) beyond deer concentration areas, and crossing structures (overpasses or underpasses) should be located at least every 1.6 km (1.0 mi.) along the fenceline.

Fencing cannot totally preclude ungulates from entering roadways, so adequate exits established along the fenceline may further reduce DVA (Feldhamer et al. 1986). Fencing effectiveness is improved by providing an opportunity for escape to ungulates trapped on the roadway (Putnam 1997).

Reed (1995) reported that one-way gates strategically located near drainages or vegetative cover were effective in allowing deer to escape highway right-of-ways (ROWs) when used in conjunction with 8-foot fences. One-way gates can be modified for use by other cervids such as elk (Reed et al. 1974a). However, Lehnert and Bissonette (1997) reported that only 16.5% of mule deer (n = 243) recorded within a right-of way between 2.3 meter (7.5 ft) fence in Utah used one-way gates for escape, suggesting a reluctance to use the gates. They suggested that earthen ramps may prove an effective method for deer to escape highway ROWs.

Ward (1982) found that on- and off-ramps, fencing holes and erosion gaps are problem areas for concern when considering fencing as a mitigation tool. Deer guards should be installed on interchange ramps (Ward 1982). At least one new "roll-bar" deer guard has been designed but not yet tested (Reed et al. 1974b; Reed et al 1979).

Feldhamer et al. (1986) recommended that DVA reduction efforts focus on increasing the effectiveness of deer fencing and reducing the attractiveness highway rights-of ways to deer.

Fencing costs

Danielson and Hubbard (1998) reported that although fencing used in conjunction with other techniques may be the most effective strategy for reducing DVA, costs of construction and maintenance may be prohibitive, and probably will only be feasible on major roads (Putnam 1997).

Ward (1982) reported installation costs of \$240,000 for 7.8 miles (ca. \$31,000 per mile) of eight-foot game fence along Interstate 80 in Wyoming in the early 1970s. Reed et al. (1982) approximated maintenance costs for fencing to be 1% of construction costs per year. Danielson and Hubbard (1998) stated that the Iowa Department of Transportation estimated the costs of materials and installation for 8-foot chain-link fence at \$42,000 per mile (for one side of the road). BRW (1999) estimates the cost of materials and construction for 8-foot deer fencing for U.S. Highway 550 from Aztec to the Colorado border at \$10-12 per linear foot (\$52,800-63,360 per mile).

Fencing cost-benefit ratio

Reed et al. (1982) reports that even if fencing is 100% effective at eliminating DVA, there will be a certain DVA rate at which the benefits do not outweigh the costs. Reed et al. (1982) recommended that fencing be constructed if the benefit to cost ratio exceeded 1.36:1. In Pennsylvania, Bashore et al. (1985) concluded that fencing was the cheapest and most effective technique for reducing white-tail DVA along short stretches of highway.

2. Crosswalks

Crosswalks are used in conjunction with fencing to force deer to cross at well-signed specific crossing locations (Danielson and Hubbard 1998). Although not statistically validated due to lack of replication, Lehnert and Bissonette (1997) found in Utah that deer mortality from DVA

declined 42.3% and 36.8% along a 4-lane and 2-lane highway respectively, where highway crosswalks were used. They found that the lack of motorist response to crosswalk warning signs, the tendency for foraging deer to wander outside crosswalk boundaries, and the relative ineffectiveness of 1-way escape gates contributed to most deer mortalities in the treatment areas. They recommended improving crosswalk design by moving fences inward closer to the highway to allow deer more access to desirable forage along the ROW.

Danielson and Hubbard (1998) stated that complete elimination of DVA by installing crosswalks is unlikely, but found them to be a lower cost alternative to overpass and underpass construction. Lehnert and Bissonette (1997) estimated the cost of constructing deer crosswalks at \$28,000 and \$15,000 per structure for the 4-lane and 2-lane highways, respectively. These costs did not include fence or 1-way gate construction.

3. Underpasses

Underpasses are used primarily in conjunction with fencing to funnel animals to the structures (Putnam 1997). The theoretical basis for their design is that an underpass not be so long, narrow and confining as to preclude use by deer. The factor developed to measure this response is "openness effect", determined by the underpass height, times the width, divided by the length.

Reed et al. (1975) and Reed (1981) documented deer use of an underpass (openness factor of 0.31) built specifically for deer under I-70 in western Colorado. These studies determined that deer adapted to using the underpass over time, but that some deer continued to be reluctant to use the underpass. Reed et al. (1979) reported on 11 other underpasses used by deer, two of which were twin bridge structures (4.57 and 5.57 openness factor) built specifically for deer. Deer showed no reluctance using these underpasses compared to the 0.31 openness factor in the other two studies.

Ward (1982) investigated deer use of 7 underpasses in southeast Wyoming. The underpass receiving the most usage had an openness factor of 5.44. Ward (1982) suggested that deer exhibited a learning response to the underpass over time.

Danielson and Hubbard (1998) reported that for underpasses and other ROW crossing methods to be effective, structures must be located where natural wildlife corridors occur (Bruinderink and Hazebroek 1996). In Idaho, crossing structures that were not located at traditional game corridors failed to reduce DVA, and fencing to redirect deer to crossing structures outside of natural corridors were ineffective (Hanna 1992).

Reed (pers. comm.) recommends an openness factor of near 2.0 for underpasses to be effective. Reed (1995) gave underpasses a 78.5% effectiveness rating at reducing deer-vehicle accidents.

4. Overpasses

Overpasses are also used primarily in conjunction with fencing to funnel animals to the structure (Putnam 1997). A theoretical basis for design is that overpasses not preclude cervid crossing by being too high, long or narrow. The factor developed to measure this response is "bridge effect" (bridge width times the square root of the height divided by the length). Putnam (1997) stated that overpasses require a minimum width of 30 meters and must be covered with dirt and grass to be effectively used by animals.

Reed et al. (1979) investigated the willingness of deer to cross overpasses of 0.43 and 0.65 bridge effect in Colorado. Deer showed slight to moderate reluctance to cross. Reed (1995) stated that twin overpasses each with a bridge effect of 0.26 were recently constructed over I-15 in Utah specifically for deer. Location, topography, vegetative cover and lack of overhead structures were considered important factors influencing the design and construction of these overpasses.

Studies have also investigated the use of overpasses by reindeer (Klein 1971) and caribou (Child 1974). Increased protective cover on both sides of overpasses and underpasses increases the likelihood of use by deer and other wildlife, although both overpasses and underpasses require an adjustment period for deer to become accustomed to using them (Putnam 1997).

Reed (1995) gave overpasses an 88.1% effectiveness rating at reducing DVA. However, Danielson and Hubbard (1998) stated that wildlife use of overpasses appeared to be less than underpasses.

5. Reflectors

The intent of wildlife reflectors is to redirect light from vehicle headlights to the side of the highway, creating a wall of light that supposedly stops deer from entering the roadway until after the vehicle has passed. In theory, in contrast to fencing, wildlife reflectors provide a "barrier" to wildlife only when vehicles are present at night, allowing otherwise normal wildlife movements across the roadway (Danielson and Hubbard 1998, Putnam 1997).

Reed (1995) identified two types of wildlife reflectors that have been tested; a stainless steel mirror, and the Swareflex reflector, a red plastic lens developed by the Austrian firm Swarovski & Co. The hypothesis driving the development and marketing of the Swareflex reflector is that deer respond adversely to red light, since it has been suggested that a predator's eyes appear red to deer.

Reed (1995) stated that although a number of reflector studies have been conducted, most have not had adequate sample sizes or controls to differentiate temporal and/or area effects, such as changes in deer population and traffic levels. Reed (1995) cited several studies (Gordon 1969, Woodward et al. 1973, Almkvist et al. 1980, Gilbert 1982, Olbrich 1984) that concluded that reflectors were not effective at reducing DVA. Danielson and Hubbard (1998) cite other studies (Reeve and Anderson 1993, Ford and Villa 1993, Gilbert 1982, Waring et al.) that also concluded that Swareflex reflectors were ineffective at reducing DVA.

However, Schafer and Penland (1985) controlled for differential area and temporal effects (changes in deer populations, traffic levels and other environmental trends) and found a statistically significant difference suggesting that Swareflex reflectors were effective at reducing deer-vehicle accidents in Washington. This study did not, however, meet the sample size of at least 95 accidents needed to test the null hypothesis, as recommended by White (1983).

Zacks (1986) found no evidence that white-tailed deer (*Odocoileus virginianus*) responded negatively to red light generated by Swareflex reflectors. He suggested that the positive results found in Schafer and Penland (1985) and Schafer et al. (1985) were more likely the result of increased driver awareness than the effect of the reflectors on deer behavior.

Reed (1995) summarized wildlife reflector research as providing conflicting results, but suggested that the premise underlying Swareflex reflectors (that deer avoid red light) is likely flawed.

6. Wildlife warning whistles

Wildlife warning whistles are mounted on vehicles and are intended to warn animals of approaching vehicles. These ultrasonic devices operate at frequencies of 16-20 kHz (Romin and Dalton 1992, Danielson and Hubbard 1998).

Reed (1995) was aware of only a few studies specifically testing the effectiveness of ultrasonic devices at reducing DVA. Schober and Sommer (1984) found several acoustic devices ineffective, including the Sav-A-Life deer-whistle marketed in the U.S. and Canada. Romin and Dalton (1992) did not detect any differences in responses from 150 groups of free-roaming mule deer to vehicles mounted with and without Sav-A-Life and Game Tracker wildlife warning whistles. Bomford and O'Brien (1990) found that

ultrasonic devices did not perform as claimed when testing deterrents for animal damage control applications. Sales and Pye (1974) did not include ungulate species in their list of animals possessing ultrasonic sound capability. Some sources recommend low-frequency sounds (<20,000 Hz) for repelling ungulates, although deer appear to habituate to the sight and sound of traffic (Reed 1995).

Reed (1995) suggested that additional research be conducted to answer two fundamental questions: 1) do cervids possess ultrasonic hearing capabilities greater than 20,000 Hz; and 2) do cervids habituate to sound stimuli in the ultrasonic range, if it is perceived.

7. Highway lighting

Reed et al. (1979) and Reed and Woodward (1981) tested the hypothesis that increased highway lighting would reduce DVA, but found that increased illumination was not effective at reducing DVA under the conditions of their studies. Reed (1981a) concluded that increased highway illumination was not effective at reducing DVA.

8. Vegetation manipulation, intercept feeding and salt alternatives

Since highway ROWs may provide attractive food sources for deer, palatable plants and mast producing trees should not be planted (Bruinderink and Hazebroek 1996, Leedy and Adams 1982).

Hafenrichter et al. (1968) recommended streambank wheatgrass (*Agropyron riparium*) as a less palatable grass species that has been used along highway ROWs.

Pojar (1971) tested the hypothesis that reduced vegetative cover along roadsides would reduce accidents by increasing motorist visibility. Sufficient evidence was not provided by the study to support the hypothesis.

Reed (1995) reported minimal testing of the effectiveness of vegetation manipulation on DVA. Svoboda (1974) found that attempts to establish roadside plant communities unattractive to deer have not always been successful.

Wood and Wolf (1988) report that providing deer with foraging areas between bedding areas and highway ROWs may have reduced DVA by 50% in Utah. However, they recommend intercept feeding only as a short-term DVA mitigation strategy and only in areas of high deer concentrations (Wood and Wolf 1998).

Bruinderink and Hazebroek (1996) report that road salting for deicing may attract deer to highway ROWs. Feldhamer et al. (1986) recommended using deicers other than salt to reduce the attractiveness of DVA. Bruinderink and Hazebroek (1996) recommended using calcium magnesium acetate instead on sodium chloride for deicing roads.

9. Warning signs, speed limit reduction and driver education

Signs warning drivers of high-risk deer crossing areas are the most common DVA mitigation strategy (Putnam 1997). Reed (1995) stated that warning signs are a possible method to reduce DVA by increasing driver awareness and/or reducing driver speed. Mansfield and Miller (1975) concluded that 76x76 cm. symbol-type warning signs were effective at reducing DVA in 11 of 19 study areas in California. Reed (1995) states, however, that in 9 of the 11 successful areas, the differences were not statistically significant.

Pojar et al. (1975) found that mule deer-vehicle accidents were not significantly reduced by lighted, animated deer crossing signs in Colorado. Drivers apparently did see the signs but did not respond by reducing speed or increasing awareness enough to significantly affect DVA frequency. Reed (1995) reports that similar research on the effectiveness of signs in reducing DVA accidents in Sweden showed these measures to be ineffective as well (Edholm and Kolsrud 1960, Aberg 1981).

The greatest motorist speed reduction response was recorded by Pojar et al. (1975) after placing three dead deer carcasses on the highway shoulder close to a deer crossing sign. Vehicle speed was reduced by an average of 7.85 mph, but the test was discontinued for liability reasons.

No specific research has been conducted to determine the effectiveness of driver education on mitigating DVA (Danielson and Hubbard 1998, Reed 1995, Romin and Bissonette 1996). Reed (1995) suggested that even with intensive driver education using simulators or other methods, reduction of DVA rates would be minimal due to other uncontrolled conditions such as nighttime vision impediments, weather, and road conditions.

10. Chemical Repellents

Danielson and Hubbard (1998) reported that chemical repellants have been used in Europe to reduce DVA. Putnam (1997) reported that chemical repellents are sprayed along roadways in Germany to create ungulate avoidance "fences", but this method has not been tested adequately.

11. Deer herd reduction

Reed (1995) was not aware of research designed specifically to evaluate the effectiveness of hunting in reducing DVA. He suggests that both-sex hunts could reduce or eliminate subpopulations, thereby reducing or eliminating DVA occurrence, but warns that implementing this strategy could be difficult to

defend from a philosophical and public policy perspective. Waring et al. (1991) found that DVA did not decline on their study area, although the white-tail deer population was decreased.

12. Possible vehicle modifications and devices

Danielson and Hubbard (1998) reported on alternative technological devices in the testing phase that may be available in the future to deter DVA. These include: 1) modified vehicle headlights that may reduce the tendency for deer to freeze in the headlight glare, which are currently being used in Europe (low-glare headlights are illegal in the U.S.); 2) infra-red detection systems developed by General Motors that are currently being offered in some models; and 3) intermittently lighted warning signs at deer crosswalks (or high DVA areas) that are triggered by ungulate movements or body heat.

Of these techniques, Danielson and Hubbard (1998) suggest that infra-red sensing devices used in conjunction with solar-powered warning signs hold the most promise for the future for reducing DVA. They estimate costs at \$1000-1200 per unit, with biennial replacement costs of \$7-10 per unit.

LITERATURE CITED

Aberg, L. 1981. The human factor in game-vehicle accidents: a study of driver information acquisition. Dept. of Psychology, Univ. of Uppsala, Sweden. 130 pp.

Almkvist, B., T.Andre, S. Ekblom and S.A. Rempler. 1980. Viltolychsprojektet (VIOL). Slutrapport. Statens vagverk TU 146. 117 pp.

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.

Bomford, M., and P.H. O'Brien. 1990. Sonic deterrents in animal damage control: a view of device tests and their effectiveness. *Wildl. Soc. Bull.* 18:411-422.

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

BRW Consulting, 18 Jun 1999. Review of proposed deer fencing and wetlands replacement, U.S. Highway 550 project. Meeting minutes. Two Park Square, 6565 Americas Parkway, N.E. Suite 610. Albuquerque, NM 87110

Child, K.N. 1974. Reaction of caribou to various types of simulated pipelines at Prudoe Bay, Alaska. Pages 305-812 In V. Geist and F. Walther, eds. The behaviour of ungulates and its relation to management. Intl Union Conserv. Nature and Nat. Resour., Morges, Switzerland. 940 pp.

Conover, W.C., 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.

Danielson, B.J. and M.W. Hubbard. 1998. A Literature Review for Assessing the Status of Current Methods of Reducing Deer-Vehicle Collisions. A report prepared for The Task Force on Animal Collisions, Iowa Department of Transportation and Iowa Department of Natural Resources. 25pp.

Decker, D.J., K.M. Loconti Lee, and N.A. Connelly. 1990. Incidence and costs of deer-related vehicular in Tompkins County, New York. HDRU Series 89-7, revised Feb. 1990. Hum. Dimensions Res. Unit, Dep. Nat. Resour., N.Y. State Coll. Agric. and Life Sci., Cornell Univ., Ithaca. 22pp.

Edholm, S., and B. Kolsrud. 1960. Hastighet pa vagar genom vilstrak. Statens vagverk.

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.

Free, S.L., and C.W. Serveringhaus. Undated. Report on the effectiveness of a "deer proof" fence on the New York State thruway. Unpubl. Rep. P-R Proj. W-89-R-3, New York Dept. Environ. Conserv., Albany. 22pp.

Gilbert, J.R. 1982. Evaluation of deer mirrors for reducing deer-vehicle collisions. Federal Highway Administration, Offices of Research and Development. Rep. No. FHWA/RD-82/061. 13pp.

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.

Gordon, D.F. 1969. "Deer mirrors"-a clearer picture. Colo. Div. Game, Fish and Parks. Game Inf. Leaflet. 77. 3pp.

Hafenrichter, A.L., J.L. Schwendiman, H.L.Harris, R.S. MacLauchlan, and H.W. Miller. 1968. Grasses and legumes for soil conservation in the Pacific Northwest and Great Basin states. Agr. Handbook 339. Soil Conservation Service, Wash., DC. 69pp.

Hanna, P. 1982. The impact of Interstate Highway 84 on the Sublett-Black Pine migratory 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. 97pp.

Klein, D.R. 1971. Reaction of reindeer to obstructions and disturbances. Science 173:393-398.

Lavsund, S. and F. Sandegren. 1991. Moose-vehicle relations in Sweden-a review. Alces 27:118-126.

Leedy, D.L., and L.W. Adams. 1982. Wildlife considerations in planning and managing highway corridors. Federal Highway Administration, Offices of Research and Development. Rep. No. FHWA-TS-82-212. 93pp.

Lehnert, M.E., and J.A. Bissonette. 1997. Effectiveness of highway crosswalk structures at reducing deer-vehicle collisions. Wildlife Society Bulletin 25:819-822.

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.

Mansfield, T.M., and B.D. Miller. 1975. Highway deer kill District 02 Regional study. Caltrans Environmental Branch, Sacramento. CA. 49pp.

Muller, S. 1967. Road traffic and wildlife. *Strasse and Verkehr* 53:121-129.

Myers, G.T. 1970. An investigation of deer-auto accidents. Pages 403-437 in *Game Res. Rep.*, July Part III. Colo. Game, Fish and Parks Div. 455 pp.

Olbrich, P. 1984. Untersuchung der wirksamkeit von wildwarnreflektoren und eignung von wilddurchlassen. *Z. Jagdwiss.* 30:101-116.

Pojar, T.M. 1971. Evaluation of devices to prevent deer-auto accidents. Pages 331-339 In *Game Res. Rep.*, July Part III. Colo. Game, Fish and Parks Div. 366 pp.

Pojar, T.M., R.A. Prosen, D.F. Reed, and T.N. Woodward. 1975. Effectiveness of a lighted, animated deer crossing sign. *J. Wildl. Manage.* 39: 87-91.

Putnam, 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. *J. Wildl. Manage.* 45:542-543.

Reed, D.F. 1981a. Effectiveness of highway lighting in reducing deer-vehicle collisions. *Journal of Wildlife Management* 45:721-726.

Reed, D.F. 1995. Efficacy of methods advocated to reduce cervid-vehicle accidents: research and rationale in North America. Conference presentee lors du colloque international "Route et faune sauvage", Strasbourg, Conseil de l'Europe, 5-7 juin 1985 and Sapporo, Japan, 27 Jan 1995.

Reed, D.F. and T.N. Woodward. 1981. Effectiveness of highway lighting in reducing deer-vehicle accidents. *J. Wildl. Manage.* 45:721-726.

Reed, D.F., T.M. Pojar, and T.N. Woodward. 1974a. Use of one-way gates by mule deer. *J. Wildl. Manage.* 38:9-15.

Reed, D.F., T.M. Pojar, and T.N. Woodward. 1974b. Mule deer responses to deer quads. *J. Range Manage.* 27:111-113.

Reed, D.F., T.N. Woodward and T.M. Pojar. 1975. Behavioral response of mule deer to a highway underpass. *J. Wildl. Manage.* 39:361-367.

Reed, D.F., T.N. Woodward and T.D.I. Beck. 1979. Regional deer-vehicle accident research. *Colo. Div. Of Highways Rep. 79-11.* 61 pp.

Reed, D.F., T.D.I. Beck and T.N. Woodward. 1982. Methods of reducing deer-vehicle accidents: benefit-cost analysis. *Wildl. Soc. Bull.* 10:349-354.

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

Romin, L.A., and L.B. Dalton. 1992. Lack of response by mule deer to wildlife warning whistles. *Wildl. Soc. Bull.* 20:382-384.

Romin, L.A. 1994. Factors associated with the highway mortality of mule deer at Jordanelle Reservoir, Utah. M.S. Thesis, Utah State Univ., Logan. 75pp.

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.

Sales, G., and D. Pye. 1974. *Ultrasonic communication by animals.* Chapman and Hall, London. 281pp.

Schafer, J.A., and S.T. Penland. 1985. Effectiveness of Swareflex reflectors in reducing deer-vehicle accidents. *J. Wildl. Manage.* 49:744-776.

Schafer, J.A., S. Penland and W.P. Carr. 1985. Effectiveness of Wildlife Warning Reflectors in Reducing Deer-Vehicle Accidents in Washington State. *Transportation Research Record* 1010, TRB, National Research Council, Washington, D.C. pp.85-88.

Schober, F., and F. Sommer. 1984. Untersuchung akustischer wildwarngerate fur kraftfahrzeuge. *Z. Jagdwiss.* 30:164-176.

Svoboda, F.J. 1974. Big-game highway safety conflicts and suggested solutins. Minnesota Highway Dep., Office of Environmental Services. 27pp.

Ward, A.L., N.E. Fornwalt, S.E. Henry, and R.A. Hodorff. 1979. Effects of highway operation practices and facilities on elk, mule deer, and pronghorn antelope. *Fed. Highway Admin. Rep.* FHWA-RD-79-143. 48pp.

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 Behavioural Science* 29:215-223.

White, G.C. 1983. Sample size requirements for reflector study. Los Alamos National Laboratory, Los Alamos, NM. 4pp.

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.

Woodward, T.N., D.F. Reed, and T.M. Pojar. 1973. Effectiveness of Swareflex wildlife warning reflectors in reducing deer-vehicle accidents. Colo. Div. Wildl. 5pp.

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

Zacks, J.L. 1986. Do white-tailed deer avoid red? Premise underlying the design of Swareflex Wildlife Reflectors. Transportation Research Record 1075:35-39,41-43.

Zacks, J.L., and W. Budde. 1983. Behavioral investigations of color vision in white-tailed deer, *Odocoileus virginianus*. Investigative Ophthalmology 24, Suppl., 185.

Recommended further reading:

Forman, T.T. and D. Sperling. 2003. *Road Ecology. Science and Solutions*. Island Press, Washington, D.C. 481 pp.

Sullivan, T.L. and T.A. Messmer. 2002. Nationwide Perceptions of State Wildlife Agency and Department of Transportation Administrators Regarding Deer-Vehicle Collisions and their Management. Final Report. Jack Berryman Institute, Utah State University, Logan, UT.

Transportation Research Board of the National Academies. 2002. Interaction Between Roadways and Wildlife Ecology. A Synthesis of Highway Practice. NCHRP Synthesis 305. National Cooperative Highway Research Program. https://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_305.pdf

U.S. Dept. of Transportation, Federal Highway Administration. 2002. Wildlife Habitat Connectivity Across European Highways. International Technology Exchange Program.

White, P.A. and M. Ernst. No date. Second Nature. Improving Transportation Without Putting Nature Second. Surface Transportation Policy Project. Defenders of Wildlife, Washington, D.C.