Evaluation of Strategies Designed To Reduce Deer-vehicle Collisions:

An Annotated Bibliography

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Literature Review

EVALUATION OF STRATEGIES DESIGNED TO REDUCE DEER-VEHICLE COLLISIONS

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INTRODUCTION

Upon review of literature related to deer-vehicle collision reduction strategies, several prominent themes are evident: (1) Of the mitigation technologies previously studied, fencing of adequate height combined with the proper wildlife crossing structures is the most effective method for reducing deer-vehicle collisions while providing a semi-permeable road/landscape interface. (2) Areas in need of improvement on an international level include: monitoring of deer-vehicle collision rates; scientifically rigorous evaluation of reduction strategies; and communication and cooperation among governments, wildlife researchers, highway managers, motorists, and others involved in the issue of deer-vehicle collisions.

To develop solutions aimed at reducing the occurrence of deer-vehicle collisions, we must enhance our understanding of the factors that result in hazardous encounters between deer and motorists. This requires a unique cooperative effort among disciplines to design, successfully implement, and refine mitigation techniques. Ultimately, we should possess a collection of strategies that were developed with consideration for the specific behavioral and physiological traits of deer and motorists alike.

Literature Reviews On Deer-vehicle Collision Mitigation – Annotated Bibliography

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

Bruinderink and Hazebroek evaluated literature related to ungulate-vehicle collisions in Europe, the U.S., and Japan. They argued that the relationship suggested in most studies, between the incidence of ungulate-vehicle collisions and traffic volume, is confounded by population dynamics, changes in traffic volume, and sampling intensity. Bruinderink and Hazebroek concluded that successful design of mitigation strategies is contingent on consideration for the life history features of the target species. They found no strong evidence of the effectiveness of passive warning signs, warning reflectors, or scent or acoustic deterrents. For high volume roads, they recommended the use of fencing combined with wildlife passage structures to deter ungulates from roadways. For secondary roads, they recommended seasonal application of intermittently lighted warning signs triggered by ungulates entering the roadway corridor. They also encouraged the implementation of driver education programs.

Damas & Smith Limited. 1982. Wildlife mortality in transportation corridors in Canada's national parks. Main Report, Volumes 1 and 2.

Damas & Smith Limited conducted a comprehensive literature review on deer-vehicle countermeasures. They identified mitigation strategies that proved most effective in minimizing deer-vehicle collisions in Canada, the United States, and Europe and recommended experimental control techniques for selected national parks in Canada. In their assessment, they recognized fencing to "have the widest applicability and highest overall effectiveness" of techniques tested. However, they also regarded fencing as maintenance intensive and restrictive to wildlife movements without the installation of proper animal crossing devices. They recommended the testing of the following strategies for reducing deer-vehicle collisions in Canada's national parks: chemical repellents, a microwave animal crossing detection system with flashing warning signs, alternatives to road salt de-icing agents, and a public information campaign.

Danielson, B. J., and M. W. Hubbard. 1998. A literature review for assessing the status of current methods for reducing deer-vehicle collisions. Task Force on Animal Vehicle Collisions, Iowa Department of Transportation, and Iowa Department of Natural Resources.

Danielson and Hubbard suggested that the primary problems with previous research on deer-vehicle collisions were "(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". Of those studies deemed statistically valid, Danielson and Hubbard concluded through a literature review that properly maintained fencing coupled with wildlife crossing structures was the most effective mitigation strategy for reducing deer-vehicle collisions on main roads. They indicated that such structures should be monitored for sufficient wildlife use with infrared detection systems. Danielson and Hubbard further suggested that public awareness campaigns and driver awareness programs should be evaluated in future research efforts.

Deer Vehicle Collision Working Group. 2000. Deer Vehicle Collision Working Group Conference Final Report.

The Wisconsin Departments of Transportation and Natural Resources and the Sand County Foundation invited leaders in insurance; highway safety, management, and engineering; landscape ecology; local government; law enforcement; and related fields from their region of the U.S. and Canada to participate in a working session to address the issue of >60,000 deer-vehicle collisions annually on Wisconsin roadways. Working Group participants developed and committed to a pathway of action, which promised to develop a comprehensive public education program related to deer-vehicle collisions; support of statewide deer herd reduction; create a "toolbox" of possible actions that could be tailored and implemented to reduce deer-vehicle collisions at a specific site; and to create a regional clearinghouse to disseminate validated information on deer-vehicle collisions. They also identified areas requiring research, these included: (1) determine if local deer herd reduction can lower deer-vehicle collision rates; (2) determine if fencing and other barriers help prevent deer-vehicle collisions; (3) determine if modifying road corridor habitat can reduce deer-vehicle collisions; (4) create a "Center for Research Excellence" to address scientific standards, research quality, and funding.

Hedlund, J. H., P. D. Curtis, G. Curtis, and A. F. Williams. 2003. Methods to reduce traffic crashes involving deer: what works and what does not. Insurance Institute for Highway Safety.

Hedlund et al. conducted an intensive review of literature pertinent to deer-vehicle collisions and concluded that fencing combined with overpasses and underpasses was the only scientifically proven and publicly accepted method. However, they also stated that fencing will not eliminate deer entering roadways and such strategies are expensive to construct and maintain. Their review identified other possible mitigation strategies that require further testing; these included: herd reduction, roadside clearing, temporary and active warning signs, at-grade crossings for deer combined with signage, infrared driver vision. Hedlund et al. categorized reflectors, roadside lighting, intercept feeding, and repellents as methods with limited demonstrated effectiveness. They suggested that quality research investigating the response and habituation of deer to light beams and reflectors would be useful. Hedlund et al. determined that deer whistles and deer flagging signs were not effective, and general education, passive signs, and speed limit reduction had no promise.

Jacobson, S. L. 2002. The Wildlife Crossing Structures Toolkit: a compilation of mitigation techniques for highway-related impacts to wildlife. Proceedings of The Wildlife Society Annual Conference 9:143-144.

The wildlife crossing toolkit located at http://www.wildlifecrossings.info is a searchable internet database resource for biologists and highway planners, which provides information on strategies to mitigate wildlife highway mortality and increase highway permeability for wildlife. Information in the Toolkit includes wildlife species-specific information relative to passage structure design and materials, criteria for mitigation technique use, and effectiveness.

Premo, K. F., and D. B. Premo. 1995. Investigating methods to reduce deer-vehicle accidents in Michigan. U.S. Department of Transportation, Federal Highway Administration Report No. FHWA-MI-RD-96-02.

Premo and Premo rated deer-vehicle collision mitigation strategies with potential for use in Michigan using information gathered during a literature review and by interviewing individuals with expertise related to deer-vehicle collisions. Methods with very good potential to reduce deer-vehicle collisions in Michigan included deer population management, modifying right-of-way vegetation and width, right-of-way clearing, warning signs, limiting driver speed, driver education, and public awareness programs. Those strategies with good potential to be effective included artificial deer feeding restrictions, modified agricultural and forestry activities, habitat modification, and alternative highway design.

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

Putnam reviewed literature pertaining to deer-vehicle collision mitigation techniques used in the U.S. and Europe; these included deer warning signs, roadside reflectors, chemical repellents, sound-scarers, roadside fencing in combination with crossing structures and one-way gates, and management of roadside vegetation. Putnam concluded that for major roadways with consistently high traffic volumes, fencing was the only effective measure to significantly reduce deer crossings. He noted, however, that underpasses and overpasses should be installed with fencing constructed in a manner, which funnels animal movements to the structures to increase use and habitat connectivity. Also, one-way gates proved necessary to allow an escape passage for animals trapped in the roadway corridor. Underpass dimensions should be at least 4 m X 4 m with floor material of a natural substrate and cover-type habitat near the entrances. Putnam acknowledged that fencing and crossing structures often are prohibitively expensive for most highway projects. Although Putnam indicated that previous studies of roadside reflectors provided inconsistent conclusions, he suggested that reflectors may offer a less-expensive alternative to fencing on roads with light traffic.

Note: Animals become trapped in roadways by breaching fences at weak spots or by entering at the end of the fence. One-way gates generally are constructed of metal tines or prongs, which form a smooth funnel that flexes by spring tension in the intended direction of use and a narrow, fixed-position, pointed opening in the opposite direction. For one-way gates to be effective, the devices must be adjusted properly through spring tension and initial opening width to allow passage of the target animals only in the intended direction of travel (inside the roadway corridor to the right-of-way on the outside). This is a difficult task considering the size differences among sex and age classes of deer. Studies reporting that some animal use of gates was in both directions are indicating that the one-way gates were not totally effective.

Reed, D. F., T. N. Woodard, and T. D. Beck. 1979. Regional deer-vehicle accident research. U.S. Department of Transportation, Federal Highway Administration Final Report No. FHWA-CO-79-11.

Reed et al. evaluated the effectiveness of underpasses and overpasses, deer guards, deer fence length, highway lighting, and animated deer crossing signs in reducing mule deer-vehicle collisions on Colorado highways. They concluded that 2.44-m high deer fencing used in combination with sufficiently large underpasses or strategically placed one-way gates was the most effective method for averting deer-vehicle collisions. Deer guard prototypes were constructed either of steel rails with alternating black and white paint, large tire tubes, smaller bicycle inner tubes, or a black and white painted ray pattern. None of the deer guard designs eliminated deer crossings. Segments of 2.44-m high deer fence with one-way gates were effective in reducing deer-vehicle collisions along those sections, however, this study made no comparisons among different fence segment lengths or heights or the tendency for deer to make end runs around fences relative to segment length. Lighted, animated deer crossing signs and highway lighting did not affect driver behavior.

Note: Deer guards are a modified version of cattleguards. Both devices are placed in crossings over an excavated area of a certain depth and are designed to exclude hoofed animals while facilitating normal vehicle or pedestrian traffic. Guards have alternating lateral slats and openings spaced regularly for a total distance, which is greater than the distance that may be jumped by the animal targeted for exclusion. The slats may be sloped to make traction for hooves difficult. The excavated pit beneath the guard typically is deep enough so the target animal cannot touch the bottom through the open spaces.

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.

Romin and Bissonette distributed mail surveys to the 50 U.S. state natural resource agencies to request estimates of deer (not reported by species) killed annually on highways, the source of the estimates, and information about methods used to reduce deer-vehicle collisions. They reported that of the 43 state agencies that responded, statistics on deer kills had limited quantitative basis and were highly variable and inconsistent among agencies. They conservatively estimated that the deer road-kill for 1991 was 500,000 deer, and deer road-kills had increased in the 26 of 29 states that had suitable trend data for 1982-1991. Nearly all respondent states had used some sort of mitigation technique; two states used highway lighting, three hazed deer, six altered habitat, seven set lower speed limits, seven built or modified underpasses or overpasses, 11 used mirrors, 11 built deer exclusion fencing along roads, 20 used warning whistles, 22 used public awareness programs, 22 installed swareflex reflectors, and 40 used deer-crossing signs. Thirteen respondents indicated their state had not conducted a scientific evaluation of these techniques. No state reported a scientific evaluation of the effects of reduced speed limits, hazing, or public awareness programs.

FENCES AND WILDLIFE CROSSING STRUCTURES

Roadside fencing is arguably the most studied of devices implemented to reduce the incidence of deer-vehicle collisions. Most research has indicated that fences are not an absolute barrier to deer, and only serve to reduce the number of animals entering the roadway. Conventional wire fencing must be at least 2.4 m high to limit the ability of deer to jump over it.

Alternative low-in-height fence designs, such as solid barrier fencing and non-traditional configurations of electric fence, may provide a less-expensive fencing option to exclude deer from roadways and other areas. Construction of fencing is prohibitively expensive for many applications, and regular maintenance is both costly and necessary for effectiveness. Gaps created by weather events, humans, and animals are quickly exploited by deer, and may create "hotspots" for deer-vehicle collisions when deer enter the roadway corridor and are unable to locate an escape. Although fencing is not a complete barrier to deer, its presence may severely limit the natural movements and gene flow of deer populations and of other wildlife species. Fencing coupled with a variety of underpasses, overpasses, road-level crosswalks, one-way gates, and other strategies has been tested to allow animals to cross roadways at controlled areas along fenced highways. Crossing structures have proven most successful when used where traditional migratory routes of mule deer, elk, and other migratory species intersect highways. An intimate understanding of the proper physical design, location, and integration into the habitat of crossing structures at a particular location is necessary to encourage utilization by the targeted wildlife species.

<u>Fences and Wildlife Crossing Structures - Annotated Bibliography</u>

Barnum, S. A. 2003. Identifying the best locations to provide safe highway crossing opportunities for wildlife. Pages 246-252 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University.

Barnum used track counts along road shoulders and at highway underpasses to evaluate the characteristics of areas used as animal crossings on U.S. 24 and Interstate 70 in Colorado.

She correlated concentrated crossing areas to features of the surrounding landscape and roadside habitat using Geographic Information Systems-based simulations. Barnum identified a strategy for effectively identifying crossing locations along highways, which included: use habitat suitability as the primary indicator of crossing activity; consider how landscape structure interacts with habitat suitability to increase or decrease the potential level of area use by a particular species; consider how the design of the existing highway interacts with habitat suitability and landscape structure to influence animal crossing behavior; synthesize above information by mapping the landscape and roadway features known to be associated with crossing by species targeted for mitigation efforts. Barnum cautioned that each planning project should be approached individually with wildlife considerations incorporated into initial project design after consultation with individuals with expertise relative to the particular area and animal species.

Belant, J. L., T. W. Seamans, and C. P. Dwyer. 1998. Cattle guards reduce white-tailed deer crossings through fence openings. International Journal of Pest Management 44:247-249.

Belant et al. tested the effectiveness of cattle guards as deer exclusion devices at openings in a 2.44-m fence surrounding an airport runway. They used infrared monitors to record deer crossings at the sites during pre- and post-installation periods, which were each two weeks in duration. The mean daily number of deer crossings after installation of cattle guards was reduced by $\geq$88%.

Bellis, E. D., and H. B. Graves. 1978. Highway fences as deterrents to vehicle-deer collisions. Transportation Research Record 674:53-58.

By conducting periodic spotlight counts, Bellis and Graves monitored white-tailed deer use of a 9.7-km portion of interstate highway right-of-way in central Pennsylvania that was fenced with 2.3-m high woven-wire mesh. They concluded that even fully maintained fencing was not a barrier to deer, and suggested that a continuously high traffic volume was responsible for the low incidence of deer-vehicle collisions on the highway by creating a "moving fence that inhibits deer from moving into traffic lanes".

Brudin, C. O. 2003. Wildlife use of existing culverts and bridges in northcentral Pennsylvania. Pages 344-352 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University.

Brudin monitored drainage box culverts, arch culverts, and bridges where existing Pennsylvania highways crossed riparian areas to determine wildlife use of the structures and to define ideal characteristics of underpasses to promote wildlife use of the corridors. During phase I of the project, Brudin used infrared cameras to monitor existing underpasses in the fall during two five-day periods each separated by a month. White-tailed deer used only one of nine underpasses, and this was the largest culvert with an arch shape that was 5.8-m high by 5.8-m wide and 76.2 m long. However, other species including small and medium mammals and humans used this and all of the other structures. To better determine what size drainage culverts would most likely be used as underpasses by white-tailed deer, Brudin identified and studied 20 culverts with openness indices (openness = (width * height) / length) of 0.5 and greater. White-tailed deer were photographed in nine of 20 (65%) culverts. Black bears were observed in two culverts, and humans were observed in three culverts. The average dimensions of those culvert structures used by deer was 2.5 m in height, 4.7 m wide, and 50 m in length. Brudin detected no deer use of culverts > 87.1 m in length, and recommended increasing height and width dimensions when length of the culvert is increased to offset a narrow openness index. Brudin further suggested tying right-of-way fencing at least 2.4 m in height into underpass openings to direct wildlife movements into the structures.

Clevenger, A. P., and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14:47-56.

Clevenger and Waltho used track counts to monitor animal use of 11 wildlife underpasses, including nine open-space cement underpasses and two metal culverts, over a 35-month period in Banff National Park, Canada. They estimated expected crossing frequencies of wolves, cougars, black bears, grizzly bears, mule and white-tailed deer, elk, and moose from three models: radio telemetry locations; pellet counts; and habitat-suitability indices. They derived species-performance ratios for each species at individual underpasses by dividing observed crossing frequencies by expected crossing frequencies and then tested the null hypothesis that performance ratios did not differ between species. If the null hypothesis was rejected, they determined which underpass attributes (e.g. structural variables, noise level, landscape variables, and a human-use index) were most closely associated with species-performance ratios. Species use of underpasses was explained weakly by structural attributes. The only strong correlation observed was a negative relationship between wildlife use of an underpass and human activity.

Falk, N. W. 1975. Fencing as a deterrent to deer movement along highways. Dissertation, Pennsylvania State University, University Park, Pennsylvania, USA.

and

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.

Falk et al. concluded that 2.3-m high woven-wire mesh highway right-of-way fencing did not provide an effective barrier to deer along an interstate highway in central Pennsylvania. Using track counts in snow and soft soil, they observed high rates of deer crossing activity at fence openings near the ground.

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.

Feldhamer et al. monitored white-tailed deer along a 40.2-km section of interstate highway right-of-way in Pennsylvania with two heights of woven-wire fencing (2.7-m and 2.2-m). They regularly monitored 22 radio-collared deer that were captured within the right-of-way, conducted 36 spotlight surveys to document deer use of right-of-ways, and obtained kill locations for 100 road-killed deer within the test section of highway. They concluded that the 2.7-m high fence reduced the number of deer on the right-of-way, but did not decrease the number of road-kills in that section.

Ford, S. G. 1980. Evaluation of deer kill mitigation on SIE/LAS-395 (1976-1979). U.S. Department of Transportation, Federal Highway Administration Report No. FHWA-CA-TP-80-01.

The California State Department of Transportation developed this project to determine the effectiveness of a combination of deer-crossing underpasses, "deer-proof" fence, and one-way deer gates in preventing deer-vehicle collisions involving migrating mule deer. The structures were designed to accommodate deer migration, heavy equipment travel, and cattle passage under the highway. Three 13.2-km long sections of 2.13-m high fencing were constructed 1.6 km apart along four-lane U.S. Highway 395 in southern California. The fencing was composed of 1.83-m high woven fabric topped with three strands of high-tensile smooth wire, and was designed to direct migrating deer toward the underpasses. The fenced underpass corridors were 6.1 m wide and 104 m long. One-way gates were installed in pairs at nine locations on each fence line to allow deer trapped within the highway corridor access to outside the fence. Ford monitored deer use of the mitigation areas with track counts along fences and at crossing devices during spring migrations from 1976 through 1979. Track counts indicated that the crossing structures were very effective in safely directing deer crossings. However, it took three years for deer to adjust their movements to the structures rather than making extensive lateral movements to fence ends. In treatment areas pre-installation of the mitigation devices, deer-vehicle collisions averaged 10.8/year. During the three years post-installation, deer-vehicle collisions averaged 2.6/year, and Ford attributed seven of the nine collisions to a rancher's access gate being left open.

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

Twenty-four wildlife underpasses were installed at an average spacing of 1.43 km along a 64-km fenced portion of Interstate 75 in Florida in attempts to reduce roadway mortality of the endangered Florida panther. The fencing was 3.4 m high galvanized chain–link topped with a 1-m overhang of three strands of barbed wire. Underpasses were 21.2-25.6 m wide by 48.5 m long including the open median separating the two bridges elevating traffic 3-4 m above the ground. Foster and Humphrey examined wildlife utilization of four of the underpasses with infrared-triggered wildlife cameras installed within the underpasses. They identified crossings by panthers, bobcats, white-tailed deer, American alligators, raccoons, black bears, and numerous bird species and concluded that underpasses reduced fragmentation of animals' home ranges and prevented animal-vehicle collisions. Foster and Humphrey stressed that placement and spacing must consider the specific movement patterns of wildlife within a particular area and fence maintenance is integral to the success of a fence-underpass combination strategy.

Gallagher, G. R., H. A. Keen, and R. H. Prince. 2003. Effectiveness of a perceived solid barrier as an exclusion fence to prevent white-tailed deer damage. Proceedings of the Wildlife Damage Management Conference 10:23-29.

Gallagher et al. tested the hypothesis that a virtually solid barrier of burlap cloth would provide an effective exclusion fence for free-ranging white-tailed deer in northwest Georgia. They monitored corn consumption at treatment and control feeders and used infrared game monitors to record deer events within three plots consisting of two, 10 m X 10 m squares established in pastures. Following a pre-conditioning period, data were collected during baseline periods during 10 days prior to two experimental phases. During the first experimental phase, burlap at a height of 1.7 m was secured with wire ties to a single strand of high-tensile wire strung from four corner posts. Deer use of treatment plots was effectively eliminated (100%) over a 30-day period. During the second experimental phase, two of the three plots were reestablished 45 days later. Fence heights began at 65 cm and were raised 15 cm every five days until reaching 1.7 m in height. At a fence height of 1.7 m, corn consumption decreased by 30%. They suggested that a visually solid barrier may serve as an effective deer exclusion fence.

Gordon, K. M., and S. H. Anderson. 2003. Mule deer use of underpasses in western and southwestern Wyoming. Pages 246-252 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University.

Gordon and Anderson monitored mule deer use of six livestock and machinery underpasses on Interstate Highway 80 and one experimental wildlife underpass on U.S. Highway 30 in Wyoming. The underpasses were all located along sections of roadway with 2.4-m high fencing. They changed the inside dimensions of the experimental wildlife underpass during periods ranging from five to 20 days. Mule deer used only one underpass along Interstate Highway 80, and that structure had the highest openness ratio (openness = (width * height) / length) of all the machinery and livestock underpasses tested. Based on mule deer use of the experimental wildlife underpass during alterations of its dimensions, Gordon and Anderson recommended that future underpasses in that area be at least 6.1 m high and 2.4 m wide.

Keffer, K. C., K. M. Gordon, and S. H. Anderson. 2003. Mule deer response to a highway underpass in Nugget Canyon, Wyoming. Proceedings of The Wildlife Society Annual Conference 10:161.

In 2001, on U.S. Highway 30 in Wyoming, a mule deer underpass was constructed with dimensions of 6.10-m wide by 3.05-m high and 18.29-m long. This crossing replaced a passage, which consisted of a gap in a 11.27-km long, 2.44-m high fence. They used an infrared camera monitoring system to assess mule deer use of the underpass structure relative to variations in underpass height and width. Nearly 1,500 mule deer used the underpass in the fall of 2001 and spring 2002, and 1,338 mule deer used the underpass during fall 2002. Repel rates (approaches with no passage) and aversion to decreased openness of the underpass was less during fall 2002 than during spring 2002 and fall 2001, perhaps indicating that deer became more accustomed to using the structure over time.

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

Knight et al. evaluated elk use of different types of modifications to four-strand barbed-wire fences in rangelands. They inferred that directing elk crossings to desired locations where the modified fence would be easier for elk to cross would result in less fence damage and reduced overall fence maintenance costs. They stretched sewing thread across the 15 m wide experimental openings and maintained track beds on both sides to monitor free-ranging elk use of crossings. Broken thread and elk tracks on both sides of a fence indicated that elk crossed the opening. The modified fence crossings used most by elk had the top wire attached to the second wire, which resulted in a lower (80 cm) crossing height than the adjacent unmodified fence (100cm). These modifications were economical and only required supplies to attach the wires together.

Land, D., and M. Lotz. 1996. Wildlife crossing designs and use by Florida panthers and other wildlife in southwest Florida. Proceedings of the Florida Department of Transportation/Florida Highway Administration Transportation-related Wildlife Mortality Seminar.

Land and Lotz examined wildlife use of highway underpasses designed to mitigate roadway mortality of endangered Florida panthers on State Road 29 and Interstate 75 in southwest Florida. The two State Road 29 underpasses consisted of a pre-formed concrete box culvert 2.4 m high, 7.3 m wide, and 14.6 m long. The culvert rested at ground level and the roadway gradually rose over the structure. The crossing also included a concrete span that formed a bridge across the canals adjacent to and on each side of the roadway. The surface of the concrete span was covered with a layer of soil that supported natural vegetation. The two Interstate 75 underpasses were 21.2-25.6 m wide by 48.5 m long including the open median separating the two bridges elevating traffic 3-4 m above the ground. All underpasses were installed in conjunction with 3.4 m high chain-link fencing topped with a 1-m outrigger with three strands of barbwire. They monitored wildlife use of the underpasses with infrared trail cameras and by track counts. Underpasses on both highways were used by all medium-sized to large animals that occur in southwest Florida. White-tailed deer used the Interstate 75 underpasses more than the State Road 29 underpasses probably because of the native vegetation within the crossing and the relative openness of the Interstate 75 structures.

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

<u>and</u>

Lehnert, M. E., L. A. Romin, and J. A. Bissonette. 1996. Mule deer-highway mortality in northeastern Utah: causes, patterns, and a new mitigative technique. *In* G. L. Evink, P. Garrett, D. Zeigler, and J. Berry, editors. Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University.

Lehnert and Bissonette evaluated the effectiveness of a highway crosswalk system for reducing mortality of mule deer on a newly constructed two-lane and divided four-lane highway in northeastern Utah. Rights-of-way were fenced with 2.3-m high fencing, which restricted deer access to roadsides and directed animals to designated crosswalk zones. The crosswalk was a dirt path bordered by a field of round river cobblestones and painted cattle-guard type lines on the roadway. Four one-way gates were placed near each crosswalk to allow deer that became trapped along the highway to escape the right-of-way. A series of three warning signs was installed at a spacing of 152 m apart at each crosswalk to warn motorists of a deer-crossing zone. To evaluate the system, they: (1) monitored deer-vehicle collisions in treatment and control areas pre- and post-installation of crosswalks and compared observed and statistically expected values of deer-vehicle collisions as a basis for comparison, (2) used spotlight censuses to document deer use of the right-of-way and indirectly determine if crosswalks impeded seasonal deer migrations, (3) assessed deer behavior and movement patterns in crosswalk zones, (4) conducted motor-vehicle speed assessments to evaluate motorist response to crosswalk warning signs, (5) evaluated the efficacy of the one-way gates at enabling trapped deer to escape the right-of-way. Based on expected kill levels, deer-vehicle collisions declined 42.3% and 36.8% along the 4-lane and 2-lane highway, respectively. However, they were unable to statistically demonstrate that observed reductions resulted from crosswalk installation. Their observations of deer suggested that the system may have reduced deer use of the right-of-way by 42% and had minimal effect on deer migration. They concluded that lack of motorist response to warning signs, the tendency of foraging deer to wander outside of crosswalk boundaries and the ineffectiveness of the one-way gates contributed to most deer mortality within the treatment areas.

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.

Ludwig and Bremicker evaluated two segments of 2.4-m fence with one-way gates along new segments of interstate highway in Minnesota. The fences were 4.0-km long with nine pairs of gates and 5.5-km long with 10 pairs of gates. They monitored the segments for 18 months using automated counters and track counts at the one-way gates, and also by recording deer-vehicle collisions. Sixty-nine percent of 51 passages through the gates were from inside the fenced highway corridors to the outside (the intended direction of travel). Deer-vehicle collisions were reduced from 15 to 13 in the 4.0-km segment and from 15 to five in the 5.5-km segment. They concluded that the gates were effective in reducing deer entry into the roadway, and in allowing deer trapped within the roadway access to the right-of-way outside of the fenced corridor. The fence used in combination with one-way gates reduced the incidence of deer-vehicle collisions.

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

A series of transcontinental fences were installed in Australia beginning in the late 1800's in attempts to reduce the impacts of vermin in crop and pastoral production areas. Fences typically were constructed of wire mesh with various diameter holes and heights to restrict movements of rabbits, marsupials (mostly red and gray kangaroos), and dingoes. Although the utility of fences was much debated at the time this article was written, the author concluded that fencing served as only a partial control measure with other forms of population control as equally necessary. Further, a rigorous fence maintenance regime was considered "the keystone of effectiveness".

Palmer, W. L., J. M. Payne, R. G. Wingard, and J. L. George. 1985. A practical fence to reduce deer damage. Wildlife Society Bulletin 13:240-245.

Five experimental fence designs were tested using captive deer. Individual fence types were either a variation of non-electrified high-tensile wire; electrified, high-tensile wire; or woven-wire with an overhang extension of three strands of high-tensile wire. Deer interactions with fences were observed for 30 days. This period included food restriction for up to 14 days with food always available beyond the fence perimeter. In captivity, deer penetrated all designs except a vertical electric fence, which had five strands of high-tensile electrified wire with the first strand at 25.4 cm from the ground and each thereafter at a spacing of 30.5 cm for a total height of 147 cm. This fence, the Penn State Vertical Electric Deer Fence, then was field-tested for two years on crop fields with a history of deer damage in Pennsylvania. The fence was deemed effective in excluding deer at field sites containing alfalfa, small grains, corn, vegetables, orchards, and young coniferous trees.

Perdue, K. A., A. N. Nelson, and G. R. Gallagher. 2004. Effects of fence orientation on white-tailed deer behavior. 11th Annual Blueridge Undergraduate Research Conference, Milligen College, Johnson City, Tennessee, USA.

Perdue et al. tested the hypothesis that a slant-oriented fence would deter white-tailed deer from entering an enclosure baited daily with corn. They established three plots spaced 3 m apart and each with two paired 10-m^2 squares. During the first trial, they secured 5-cm wood slats to high-tensile wires at a 25.4-cm interval and a 40º angle to achieve a fence height of 1.2 m. On the adjacent square, they secured slats vertically to high tensile wires also at a 25.4-cm interval and a fence height of 1.2 m. For trials two and three, they reduced intervals between slats by 5 cm during each of the five-day periods. During all trials, deer consumed all corn provided (2.27 kg/day). Data from infrared game monitors indicated that during trials one and two deer entered enclosures with fences of slant design less, and during trial three there was no difference in deer entrance of enclosures regardless of fence type. During trials one and two, they observed deer jumping and penetrating both fence types. During trial three, deer penetrated and jumped vertical fences, but only jumped the slant fence configuration. Perdue et al. concluded that the slant fence type limited deer movement through the fence, but deer visual acuity was sufficient to allow deer to jump slanted fences at a height of 1.2 m.

Peterson, M. N., R. R. Lopez, N. J. Silvy, C. B. Owen, P. A. Frank, and A. W. Braden. 2003. Evaluation of deer-exclusion grates in urban areas. Wildlife Society Bulletin 31:1198-1204.

The Florida Department of Transportation instituted a system of highway fencing, underpasses, and access-road deer exclusion grating in attempts to reduce endangered Florida Key deer mortality on roadways in the Florida Keys. Peterson et al. evaluated three types of 6.1-m X 6.1-m bridge grating for deer-exclusion efficiency at access roads by monitoring attempted Key deer crossings of the structures. Through observations with infrared trail cameras of deer attempting crossings to reach automatic feeders, they determined that grating with 10.1 cm X 12.7 cm openings with diagonal crossmembers were 99.5% effective for Key deer exclusion and also the safest for pedestrians and cyclists.

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.

Puglisi et al. examined the characteristics of 874 white-tailed deer mortality sites along a 503.7-km stretch of Interstate 80 in Pennsylvania. The location of highway fencing was the most highly correlated variable determining where highway mortality occurred. The highest deer mortality occurred where the fence was located at the edge of a wooded area or within 22.9-m from the nearest wooded area, and the lowest deer mortality occurred where the fence was > 22.9-m from the nearest wooded area.

Quinn, L. J., and D. J. Smith. 2003. Evaluation of animal passage through highway drainage culverts and designing wildlife underpasses. Proceedings of The Wildlife Society Annual Conference 10:221.

Quinn and Smith conducted three studies of animal passage across highways. From 1989-1991, they used radiotelemetry (species of marked animals not stated) and infrared remote cameras to monitor underpasses on Interstate 75 in Florida primarily designed to reduce roadway mortality of the endangered Florida panther. They observed over 800 passages by species other than Florida panthers. Surveys of road-killed vertebrates indicated a reduction of >3,300 road-killed vertebrates to <2,000 from pre-construction to post-construction of a roadside barrier wall and culvert underpass system at the Florida Payne's Prairie State Reserve. After installation of the underpass system, they observed 51 wildlife species using new and old culverts, whereas they observed only 28 species passing through existing culverts prior to installation of the new structures.

Reed, D. F., T. M. Pojar, and T. N. Woodard. 1974. Use of one-way gates by mule deer. Journal of Wildlife Management 38:9-15.

Reed et al. tested variations of a one-way gate, which was designed to allow mule deer that breached a 2.44-m fence and became trapped within a highway corridor to escape through the fence and away from the highway. They conducted preliminary tests with captive mule deer, which were required to pass through gates to reach food and water. Eight gates of the type deemed most effective were installed in 2.44-m high fences adjacent to Interstate 70, near Vail, Colorado. The 2.4 km parallel fences were used in conjunction with a deer underpass in attempts to funnel the passage of mule deer during spring and fall migrations. During a 3-year period, 96% of 558 passages through the gates were in a one-way direction away from the highway (the intended direction of use).

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

Reed evaluated mule deer use of a highway underpass (height = 3.05 m, width = 3.05 m, length = 30.48 m) and the extent of their behavioral reluctance associated with entering the structure during periods with and without artificial illumination inside the underpass. The underpass was constructed to allow migrating mule deer to safely cross under a four-lane interstate highway near Vail, Colorado. Reed et al. used video surveillance, track counts, and traffic counters to monitor deer passage during four migration periods. They estimated that the underpass was successful in allowing 61% of migrating mule deer in the area to safely cross the highway.

However, they determined that deer were reluctant to enter the underpass as indicated by a total of 4,450 deer approaches to the underpass and only 1,739 actual entrances over the entire study. Deer behavior and use of the underpass was not affected by artificial illumination.

Reed, D. F., T. N. Woodard, and T. D. Beck. 1979. Regional deer-vehicle accident research. U.S. Department of Transportation, Federal Highway Administration Final Report No. FHWA-CO-79-11.

Reed et al. evaluated the effectiveness of underpasses and overpasses, deer guards, deer fence length, highway lighting, and animated deer crossing signs in reducing mule deer-vehicle collisions on Colorado roadways. By conducting track counts at underpass openings, they determined that mule deer were more likely to use underpasses with an openness ratio (openness = (width * height) / length) > 0.6. They observed mule deer utilizing a substandard overpass bridge and then altered the structure to determine: (1) a threshold of width narrowness that would be tolerated by crossing deer, (2) whether deer would cross in the presence of overhead netting to simulate a pedestrian crossing structure, and wire mesh to prevent deer from jumping onto the road surface below the overpass. Deer readily crossed the structure even at the most narrow width of 2.48 m, and with the overhead netting and wire mesh. They tested five deer guard prototypes on captive deer released in a runway and allowed to voluntarily cross the deer guards. Each prototype was a derivation of a basic design constructed of flat mill steel (spacing not specified) to form a guard section with dimensions of 3.05 m X 3.66 m. Subsequent prototypes included: Prototype II) painting the steel rails to form an alternating black and white pattern; Prototype III) five large, black innertubes cut and sectioned longitudinally to form elongated rectangles stretched across and 15 cm above the Prototype II guard; Prototype IV) 93 rubber straps stretched parallel and all 15 cm above Prototype II guard; Prototype V) a black and white ray pattern painted on a tarp placed over Prototype I guard. They deemed none of the deer guard prototypes as effective in preventing deer crossings, however, this conclusion was based on limited data of single encounters by a range of four to fourteen individual captive deer per prototype. Fences of 2.44-m in height installed in combination with one-way gates proved effective in reducing deer-vehicle collisions provided fences were properly constructed and maintained. They recommended extending fences > 0.8-km beyond mule deer concentration areas to prevent end runs, and suggested that one-way gates be placed near vegetative cover or drainages.

Reed, D. F. 1981. Mule deer behavior at a highway underpass exit. Journal of Wildlife Management 45:542-543.

Reed observed the behavior of 298 mule deer exiting a highway underpass (height = 3.05 m, width = 3.05 m, length = 30.48 m) near Vail, Colorado during spring-summer migrations over a six-year period. About 67% of deer exhibited trotting and bounding modes (indicative of reluctance or wariness), compared to the walking mode usually observed some distance before encountering the underpass. This information combined with previous observations of deer at the entrance of the same underpass by Reed at al. (1975. Journal of Wildlife Management 39:361-367), indicated that behavioral responses of deer to the structure did not change over 10 years (1970-1979).

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

Reed et al. used benefit-cost analysis to describe the cost efficiency of 2.4-m high fencing used with underpasses and one-way gates to mitigate deer-vehicle collisions in six 1.6-km long highway projects along Interstate 70 and Colorado Highway 82 near Vail, Colorado. The average number of deer-vehicle accidents/year in the test areas pre- and post-installation of the fences was estimated from the number of deer carcasses found on or along the road. The effectiveness of the fences was estimated by assuming that the average pre-fence deer mortality would continue to occur at a constant rate were the fence not installed. The equation used in their analyses was:

$$\frac{[(1) + (2)] \times (3) \times (4) \times (5)}{(6) + [(7) \times (5)] - (8)} = \text{Benefit:Cost},$$

where (1) = cost of vehicle repair, (2) value of deer, (3) pre-fence mortality, (4) fence effectiveness (%), (5) present value given annuity, (6) cost of 2.4-m fence, (7) cost of fence maintenance, (8) cost of 1.1-m right-of-way fence needed in absence of 2.4-m fence. They did not factor in the cost of loss of human life or injury related to deer-vehicle collisions. They estimated that at a benefit:cost ratio of 1.36:1, deer-vehicle collisions rates of eight, 16, and 12 dead deer/1.6 km/year are the minimums for 2.4m fencing on one side, both sides, and both sides with an underpass, respectively.

Roof, J., and J. Wooding. 1996. Evaluation of State Route 46 wildlife crossing. Florida Cooperative Fish and Wildlife Research Unit, U.S. Biological Service Technical Report No. 54.

Roof and Wooding evaluated one experimental culvert type underpass designed to reduce roadway mortality of black bears. The inside dimensions of the crossing were 14.3 m long, 7.3 m wide, and 2.4 m high. Chain-link fencing, 3 m high topped with three strands of barbwire, was installed 0.6 km and 1.1km to either side of the underpass. Paths were bulldozed in the forest adjacent to the highway to encourage bears to walk toward the crossing. They monitored wildlife activity at the underpass by observing tracks within the dirt floor of the culvert and along disked track beds along the fencing, and by using an infrared camera within the underpass.

Also, they radio-tracked 43 radio-instrumented bears to observe their movements relative to roads. Bears used the underpass on five occasions; three crossings were by radio-collared bears. Marked bears crossed State Route 46 on 26 occasions, many of which were 100-300 m from the underpass along a river. Other species documented using the underpass included rabbit, raccoon, armadillo, opossum, gray fox, white-tailed deer, coyote, bobcat, gopher tortoise, snakes, and cattle. Sixty-nine percent of animals encountering the fence did not use the underpass, 27% used the underpass, and 4% crossed the highway by crawling under the fence or by going around the ends.

Seamans, T. W., Z. J. Patton, and K. C. VerCauteren. 2003. Electrobraid fencing for use as a deer barrier. Page 657 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University.

The Electrobraid fence is comprised of a 0.6-cm polyester rope with electrified copper wire woven throughout; the Electrobraid is carried on fiberglass posts set at 15-m intervals. Seamans et al. tested the fence by conducting one- and two-choice tests with free-ranging white-tailed deer. At each of 10 individual stations set > 1 km apart, a 5 m X 5 m site was established with Electrobraid fence forming a perimeter enclosing a feed trough with whole kernel corn. A trail monitoring device was used to count deer activity. Mean deer intrusions were <1/day at one- and two-choice sites where fence was electrified, while at non-electrified control sites, mean deer intrusions were 84-86/day. They concluded that Electrobraid fence was an effective deer barrier for the five weeks of the experiment.

Servheen, C., R. Shoemaker, and L. Lawrence. 2003. A sampling of wildlife use in relation to structure variables for bridges and culverts under Interstate 90 between Alberton and St. Regis, Montana. Pages 331-341 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University.

Servheen et al. monitored seven underpasses and three culverts along Interstate 90 in Montana during 10 months with infrared cameras and by snow-tracking. Primary users of crossing structures included white-tailed deer, mule deer, elk, skunks, raccoons, house cats, foxes, coyotes, black bear, humans, and domestic dogs. Wildlife use was most common in underpasses (openness ratings range = 27.75 to 811.63) (openess = (width * height) / length), and minimal at culverts (openness ratings range = 0.12 to 0.75). They found no relationship between wildlife use and structural dimensions of the crossing devices. Ungulates most commonly used underpasses and were not observed using culverts. Servheen et al. assumed that ungulates were reluctant to use culverts because culverts lacked suitable substrate and had a low structural openness ratio.

Silvy, N. J., and J. D. Sebesta. 2000. Evaluation of deer guards for key deer, Big Pine Key Florida. Final Report, Florida Department of Transportation.

Florida Department of Transportation developed a plan to construct fencing along U.S. Highway 1 that crosses Big Pine Key, Florida to prevent vehicle collisions with endangered Key deer. In this plan, no provisions were made to stop deer from entering the highway via the many small access roads bisecting US Highway 1. The purpose of this study was to design, construct, and test a deer guard that would allow normal passage of vehicles while preventing Key deer from crossing. Deer guard prototypes were subjected to four tests: (1) no incentive to cross; (2) extra food and water incentive to cross; (3) fawn separated from doe; (4) doe separated from mature buck. Silvy and Sebesta recommended that Key deer guards measure at least 7.3 m with the center portion raised 0.6 m above the ground and cross-member spacing of 1.9 cm or more. Further, they suggested that the ends should be sloped to facilitate vehicular traffic and that side panels should extend the length of both sides of the guard.

Singleton, P. H., and J. F. Lehmkuhl. 2000. Interstate 90 Snoqualmie Pass wildlife habitat linkage assessment. Washington State Department of Transportation Report No. WA-RD 489.1.

Singleton and Lehmkuhl used Geographic Information Systems, automatic camera surveys, documentation of wildlife use of bridges and culverts, and track surveys to assess wildlife habitat connectivity and barriers to animal movement along 56.3 km of Interstate 90 in Washington. From January 1998 to March 2000, they observed 15 species of mammals utilizing culverts to cross the highway.

Squib, P., and W. Moritz. 1999. Fencing issues in Michigan. Michigan Department of Natural Resources Wildlife Division Issue Review Paper 7.

The purpose of this paper was to review biological and social issues of fences as they pertain to management of wildlife, especially free-ranging white-tailed deer in Michigan. The publication was produced in response to inquiries to Michigan Department of Natural Resources, members of the Michigan legislature, and the Michigan Natural Resources Commission by individuals and organizations concerned with the apparent increase in construction of fences in Michigan. Squib and Moritz propose two general situations where fences specifically designed to restrict deer and other wildlife movements are in the best interest of the public. The first situation utilizes high fences to protect public health, safety, and security. The second is to protect agricultural, horticultural, or silvicultural crops. They also recognized that the state must allow landowners considerable freedom to do as they please on their private property unless such actions are proven to threaten population viability of wildlife.

Teutsch, C. 2004. Personal communication on 23 April 2004 about using Polytape Electric Fence to exclude white-tailed deer from small agricultural plots.

Chris Teutsch, a forage crop agronomist, at Virginia Polytechnic Institute and State University, used a configuration of Polytape electric fence to exclude white-tailed deer from small plots used to research ryegrass and other agricultural forage growth. The double-fence configuration had an inner layer with a strand of Polytape at 40.6 cm high and another strand at 121.9 cm high. The outer layer had a single strand of Polytape at 60.1 cm (approximately at deer nose height). Teutsch reported that the fence totally eliminated deer entry into research plots.

Ward, A. L., J. L. Cupal, G. A. Goodwin, and H. D. Morris. 1976. Effects of highway construction and use on big game populations. U.S. Department of Transportation Federal Highway Administration Final Report No. FHWA-RD-76-174.

Ward et al. used helicopter and roadway surveys and radio-telemetry monitoring to observe the behavior of elk, pronghorn antelope, and mule deer relative to Interstate 80 in Colorado. They concluded that 1.2 m high right-of-way fencing was sufficient for deterring antelope from roadways since antelope were reluctant to cross fences and use highway underpasses. Ward et al. recommended the construction of 2.4-m fencing in combination with highway underpasses to prevent mule deer and elk road crossings. They used heart rate telemetry to monitor the physiological reaction of one female and one male elk to various stimuli including gun shots, vehicle traffic, humans with and without a dog, a trail bike, and an airplane. However, they made no conclusions about the elk reactions due to limited sampling intensity.

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

Big-game fencing (2.4 m high) was installed in combination with seven wildlife underpasses along a 12.5-km section of Interstate 80 in Wyoming where annually about 1,000 mule deer crossed during spring and fall migration. Three of the underpasses were the type designed for large machinery (length = 33.5-60.7 m, width = 9.1 m, height = 4.0 m) and 4 were of a concrete box-type construction (length = 46.6-120 m, width = 3.0 m, height = 3.0-5.18 m). Ward used video surveillance cameras and track counts to document more than 4,000 mule deer passages through the underpasses during four migration periods. About 70% of the deer used the machinery underpasses to move to their winter range, and about 90% of deer used the machinery underpasses during spring migration. The remainder of deer used the box-type underpasses. The incidence of deer-vehicle collisions ranged from 37-60/year in the experiment area during the four years pre-installation of the fence/underpasses. This estimate was reduced to one deer-vehicle collision during the two years post-installation.

WILDLIFE WARNING REFLECTORS

Studies of wildlife warning reflectors have used a diversity of testing methods of various levels of scientific validity, ultimately resulting in a limited understanding of reflector efficacy. Most reflector evaluations were based on counts of deer-vehicle collisions within test sections either pre- and post-installation of reflectors; when reflectors were covered versus uncovered; or within reflectorized sections as compared to adjacent control sections. Such methods fail to consider changes in deer densities, seasonal movements, or traffic patterns. Little is known about how deer react to reflector activation or if individual animals become habituated to the devices over time. Studies that use counts of deer carcasses along roadways to assess reflector effectiveness rarely use data quality controls such as video surveillance of test sections or driver surveys to account for deer-vehicle collisions that resulted in injured deer wandering from the roadside. Beyond differences in experimental design, comparison of results among different reflector studies is further confounded by the variety of reflector models tested and the distinct spectral properties of those devices.

Wildlife Warning Reflectors - Annotated Bibliography

Armstrong, J. J. 1992. An evaluation of the effectiveness of Swareflex deer reflectors. Ontario Ministry of Transportation Research and Development Branch Report No. MAT-91-12.

Armstrong evaluated the effectiveness of Swareflex reflectors in reducing collisions with white-tailed deer on King's Highway 21 in Ontario, Canada. Along one 3-km test section, reflectors were installed at a spacing of 14.5 m apart 3.1 m from the pavement edge on both sides of the highway. In a second test section of 1.1 km, reflectors were spaced 25 m apart in lines 8 m from the edge of the pavement. Armstrong alternated covering and uncovering reflectors for one-week periods during the 54-week study. Fifty-one deer vehicle collisions occurred within the study area, but of those only 30 were during darkness. During darkness, 14 collisions occurred while reflectors were uncovered, and 16 accidents occurred when reflectors were covered and non-operational. Accident rates did not differ statistically between covered and uncovered periods or for the different reflector spacing or placement configurations.

Boyd, R. J. 1966. "Deer mirrors" - do they work?. Colorado Department of Natural Resources, Division of Game, Fish, and Parks Game Information Leaflet No. 44.

and

Gordon, D. F. 1969. "Deer mirrors" – a clearer picture. Colorado Department of Natural Resources, Division of Game, Fish, and Parks Game Information Leaflet No. 77.

Boyd tested the effectiveness of Van de Ree Deer Mirrors in reducing mule deer-vehicle collisions along U.S. Highway 6 and 24 in Colorado. Mirrors were installed at a spacing of 30.5 m between mirrors on each side of the highway along two 2-km test sections of roadway. Placement was alternating from side to side of the highway so that a mirror was present every 15.3 m along the highway. In one test section, mirrors flashed across the line of traffic. In the other test section, mirrors flashed away from the roadway. Comparison of the ratio of roadkill in the mirror section versus the control area over the eight-year study period indicated that the incidence of deer-vehicle collisions increased with mirrors in effect. They detected no difference in vehicle speeds within the test section pre- and post-installation of mirrors.

Gilbert, J. R. 1982. Evaluation of deer mirrors for reducing deer-vehicle collisions. U.S. Federal Highway Administration Report No. FHWA-RD-82-061.

Gilbert tested roadside deer mirrors constructed of a polished stainless-steel surface with a dimple at each corner and one in the center. Mirrors were placed in 12 randomly selected 0.8 km test sections along 23.8 km of Interstate 95 in Maine. Over four years only six deer-vehicle collisions involving white-tailed deer were recorded in the study area with four in the mirrored test sections and two in the non-mirrored sections. Although no statistical inferences could be made from this data, Gilbert used information from related literature to conclude that mirrors and other reflectors were ineffective deterrents to deer-vehicle collisions.

Ingebrigtsen, D. K., and J. R. Ludwig. 1986. Effectiveness of Swareflex wildlife warning reflectors in reducing deer-vehicle collisions in Minnesota. Minnesota Department of Natural Resources Wildlife Report No. 3.

Ingebrigtsen and Ludwig tested Swareflex reflectors along a 1.6-km section of Interstate 94, a four-lane highway in Minnesota. They installed reflectors at 20-m intervals 4.1 m from the edge of each road surface with a total of four rows of reflectors within the roadway corridor. They recorded collisions involving white-tailed deer for one year prior to installation and for four years post-installation. During the one year prior to reflector installation, they recorded 38 deer found dead within the study area. During the four years post-installation, 13 deer were found dead for a yearly average of 3.25 deer-vehicle collisions/year. Ingebrigtsen and Ludwig did not differentiate between deer killed during daylight or darkness during the study.

Norman, P. C. Date unknown. Reducing deer-vehicle collisions by the use of reflectors- a summary of current research and literature. Howard County, Maryland Department of Recreation and Parks Internal Report.

Norman evaluated literature related to wildlife warning reflectors and deer visual capabilities, information from personal communication with persons related to the issues, and data from reflector use in Howard County, Maryland to assess the effectiveness of wildlife warning reflectors. Although he was unable to find definitive proof, Norman suggested that it was unlikely that reflectors could be effective in altering deer behavior and reducing deer-vehicle collisions. Based on his individual assessment, Norman recommended that Howard County, Maryland cease installation of Strieter-Lite reflectors, but maintenance of the previously installed reflectors and monitoring of their effectiveness be continued.

Pafko, F., and B. Kovach. 1996. Minnesota experience with deer reflectors. *In* G. L. Evink, P. Garrett, D. Zeigler, and J. Berry, editors. Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University.

Pafko and Kovach described anecdotal trends in deer-vehicle collision data for sections of rural and suburban Minnesota highways pre- and post-installation of wildlife warning reflectors. The Minnesota Department of Transportation installed red Swareflex reflectors or an unnamed brand of white reflectors along 16 roadway sections of unknown length. Due to limited data, Pafko and Kovach did not conduct statistical analyses of the accident data. In rural areas, reductions in deer-vehicle accidents post-installation of reflectors ranged from 50% to 97%. In the suburban areas, they observed increases in deer-vehicle accident rates. They provided possible explanations for the ineffectiveness of reflectors in the suburban areas including increases in deer population size, high traffic volume, and the inadequate maintenance of reflectors.

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

Reeve and Anderson evaluated the effectiveness of Swareflex reflectors for reducing vehicle collisions with mule deer in Nugget Canyon, Wyoming. They installed 350 reflectors on both sides of a 3.2-km stretch U.S. Highway 30 at a spacing of 20 m apart on straight sections of roadway and a spacing of 10 m in curves. They established a 3.2-km control section with similar roadway configuration and incidence of deer-vehicle collisions as the test section. They compared two-week alternating periods when reflectors were covered and uncovered in the test section. Over the study period, 64 deer were killed in the test section when reflectors were covered, whereas 126 deer were killed when reflectors were uncovered. Similar numbers of mule deer were killed in the section with reflectors as the control section. Sixty-two mule deer were killed in the control section when reflectors were covered in the test section and 85 were killed when reflectors were uncovered. They concluded that Swareflex reflectors were not effective in reducing mule deer-vehicle collisions.

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

Schafer and Penland established four test sections ranging from 0.72 km to 1.08 km along highway SR395 in Spokane, Washington. Test sections were placed in areas with history of high deer-vehicle collision rates. Reflectors were mounted on 1.1-m posts set 1 m from the roadway and placed at a 20-m spacing along straight stretches of road and at a 10-m spacing in curves. Reflectors in each test section were alternately covered and uncovered at one-week or two-week intervals. Fifty-eight deer (56 white-tailed deer and two mule deer) were killed at night in the test sections. Fifty-two (90%) were killed when the reflectors were covered and six (10%) when uncovered. They concluded that Swareflex Reflectors were responsible for significantly reducing the number of deer-vehicle collisions.

Sielecki, L. E. 2001. Evaluating the effectiveness of wildlife accident mitigation installations with the Wildlife Accident Reporting System (WARS) in British Columbia. Pages 473-489 *in* Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University.

Sielecki described the Wildlife Accident Reporting System (WARS), a database used by the British Columbia Ministry of Transportation to store and analyze information on animal-vehicle collisions. In 2000, about 80% of animal-vehicle accidents in British Columbia involved white-tailed and mule deer, and the province used WARS to select areas to implement deer-vehicle accident mitigation strategies including fencing and wildlife warning reflectors. Wildlife warning reflectors have been used in British Columbia since the late 1980's at over 95 locations by 2001. Sielecki reported on trends in deer-vehicle accident rates that "were not observed as part of a controlled scientific experiment" in reflectorized (reflector type not stated, but were either Swareflex or Strieter-Lite wildlife warning reflectors) portions of highway versus equal length adjacent sections with no reflectors. When comparing 9.37-km and 7.45-km experimental sections to their respective control road sections, Sielecki concluded, "it appears the installation of reflectors did not alter the overall local accident trends" from 1985-2000. Sielecki recorded the reflected light intensity of Swareflex and Strieter-Lite reflectors, and found that all models, regardless of lens color, reflected < 0.1 lux at a distance of 2 m. Of those tested, the Strieter-Lite "new" style reflector with a clear lens had the highest intensity of reflected light. Sielecki also observed a "white first surface reflection" from the external lens surface of the Swareflex and Strieter-Lite reflectors, which had a luminance value "several times to several hundred times higher than that of coloured light from the coloured lenses".

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

Ujvári et al. examined the habituation of fallow deer to repeatedly occurring light reflections from a WEGU reflector at a supplemental feeding area in the 5,600-ha Gribskov forest, Denmark. The reflector was composed of a black plastic cover and two symmetrically sloping mirror sides each with 10 vertical rows of 4-mm mirror facets. The reflector was built into a non-reflective triangular box with the reflector placed in the middle of the long side of the box. The corner opposite the reflector was open and four bulbs were situated in another corner. Light reflections for this study were 60º for the horizontal angle and 30º for the vertical angle. An observer hidden in a shed activated the reflector remotely. This person also classified and recorded deer behaviors. On two control nights, Ujvári et al. did not activate the reflector and the fallow deer only seldom showed flight behavior or alarm. During the first experimental night, deer fled from the stimulus in 99% of the cases, but over the remaining 16 experimental nights, fallow deer exhibited increasing indifference to reflections, which was explained by habituation to the stimulus.

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

Waring et al. observed white-tailed deer road-crossing behavior in Crab Orchard National Wildlife Refuge, Illinois. Before reflectors were installed, 70% of observed deer crossed or attempted to cross a roadway bordered on one side by a cornfield and on the other by hardwood forest. After Swareflex reflectors were installed along the same stretch of roadway, 76.5% of all deer crossing attempts were completed. They observed only 14 deer making dusk to dawn crossing attempts in the presence of vehicles with reflectors in place. Of those 14, 11 continued to move toward the pavement, while the other three turned and ran back toward the woods. Dusk to dawn deer roadkills occurring in the reflector test section were the same with reflectors installed as during the two years pre-installation.

Woodham, D. B. 1991. Evaluation of Swareflex wildlife warning reflectors. Colorado Department of Transportation Final Report No. CDOT-DTD-R-91-11.

Woodham installed Swareflex reflectors along two 3.2-km test sections on State Highway 121 near Denver, Colorado. Reflectors were covered and uncovered alternately during two-week periods over three months in the fall of 1988 to test the effectiveness of the reflectors for reducing vehicle collisions with mule deer. No comparisons could be made because no deer-vehicle collisions occurred within the test area during the three-month experiment. Woodham also conducted photometric evaluations of the reflectors under field conditions at varying levels of ambient light and vehicle headlight intensities and distances. Since little was known about deer vision, for comparison purposes Woodham described how the human eye would react to visual stimulation from the reflectors. The measured luminance of the reflectors was below the threshold required for the human eye to accurately detect an object, however, the human eye would not have difficulty detecting the presence of the reflectors. Woodham further suggested that the reflectors had reduced visual impact due to their small size and the amount of time (5-6 seconds) that a reflector lit up from vehicle headlights moving at speeds of 80.1-96.5 km/hour.

Zacks, J. L. 1985. An investigation of Swareflex wildlife warning reflectors. U.S. Department of Transportation Federal Highway Administration Report No. FHWA-MI-RD-85-04.

and

Zacks, J. L. 1986. Do white-tailed deer avoid red? An evaluation of the premise underlying the design of Swareflex wildlife reflectors. Transportation Research Record 1075:35-43.

Zacks used discrimination learning to assess the spectral sensitivity of a single female white-tailed deer. The deer was trained to lick a water tube when it recognized a visual stimulus projected on a screen. Zacks results suggested that deer possess a peak in spectral sensitivity at 540-550 nm and perhaps a higher peak at 500 nm. Zacks also evaluated the behavior of 10 white-tailed deer relative to Swareflex warning reflectors. The deer were penned in a 1.4-ha enclosure and provided with an unlimited supply of commercial game feed. Water was dispensed only during daily experimental trials by a remotely controlled toilet flush valve into aluminum pans with small holes in the bottom. The rapid draining (about 1.5 minutes) of the water encouraged the deer to cross the line of reflectors. Reflectors were installed on individual posts 107 cm above the ground at a spacing of 20 m. Zacks used two automobile headlights powered at 12 volts AC through a transformer to illuminate the reflectors. During 18 sessions, Zacks recorded 720 observations of deer crossing the line of reflector posts: 264 crossings when no reflectors were installed, 256 crossings when red reflectors were activated, and 200 crossings when white reflectors were activated. No statistical difference was found among deer crossings during the three experimental conditions, thus suggesting that the reflectors were ineffective in altering deer crossing behavior.

MOTORIST WARNING DEVICES

Active and passive driver warning devices have proven largely ineffective at reducing vehicle speeds and deer-vehicle collisions. Drivers ignore the common "deer crossing" sign, a likely result of its overuse. Although reduced speeds are not the only desired effect of warning drivers about site-specific dangers associated with wildlife crossings, it is the most common method of assessing warning device effectiveness. No studies to date have assessed driver alertness or other changes in driver behavior relative to warning devices through surveys directed at motorists actually exposed to such strategies. The effectiveness of recently developed active warning systems, which only alert drivers when animals are present near the roadway, has been unclear despite the high cost of such devices. Research indicating that non-redundant command type messages impact driver behavior more than notification style messages suggests that educating drivers during periods when they are most likely to encounter roadway dangers (i.e. during the fall and spring when deer-vehicle collisions are most common) may be most effective. Such techniques should be evaluated through direct communication with drivers.

Motorist Warning Devices - Annotated Bibliography

Gordon, K. M., S. H. Anderson, B. Gribble, and M. Johnson. 2001. Evaluation of the FLASH (Flashing light animal sensing host) system in Nugget Canyon, Wyoming. Wyoming Cooperative Fish and Wildlife Research Unit.

and

Gordon, K. M., and S. H. Anderson. 2001. Motorist response to a deer-sensing warning system in western Wyoming. Pages 549-555 *in* Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University.

<u>and</u>

Gordon, K. M., M. C. McKinstry, and S. H. Anderson. 2004. Motorist response to a deer-sensing warning system. Wildlife Society Bulletin 32:565-573.

Gordon et al. evaluated the effectiveness of a flashing light animal sensing host (FLASH) and a geophone deer detection system in identifying deer crossing a highway at a fence opening. The FLASH consisted of infrared sensors that detected animal body heat, which activated flashing lights at deer crossing signs 300 m to either side of the crossing to warn motorists of animals in the roadway. They also conducted a series of experimental manipulations to determine motorist response to the FLASH. The geophone deer detection system detected ground vibrations caused by animals crossing the opening. Deer did not cause 50% of FLASH activations, whereas the geophone system did not activate falsely. Nighttime motorists reduced their speed (6 km/hour) the most (6%) when the FLASH operated normally. They detected reduced speeds the least (7%) for the activated warning signals. Vehicle speed was reduced (20%) when deer or deer decoys were present adjacent to the road and the warning signs were activated.

Huijser, M. P., and P. T. McGowen. 2003. Overview of animal detection and animal warning systems in North America and Europe. Pages 368-382 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University.

Huijser and McGowen reviewed literature related to animal detection and animal warning systems to identify locations in North America and Europe where such strategies have been implemented and they gave an assessment of each system's operation and effectiveness. As of September 2003, they identified 27 locations where systems were or had been in place, and another 20 locations where systems were to be installed. They defined animal detection systems as those devices, which sensed large animals near the roadway and then warned drivers usually with active signage. Animal warning systems were those devices, which detected vehicles and then warned animals with visual or auditory signals. Of those systems evaluated, Huijser and McGowen found that only a few operated well and likely reduced animal-vehicle collisions. Those systems, which proved reliably operational, included passive infrared systems in Switzerland; microwave radar devices in Finland; a geophone system, which detected ground vibrations of moving ungulates in Wyoming, U. S.; and a system in which the sensing of nearby radio-collared lead cows in elk herds triggered warning activation in Washington, U.S. For systems to operate properly and reduce the incidence of false detections, many design and maintenance issues must be addressed including weather conditions, vehicle engine heat, and small animals and birds using the structures for nesting thus interfering with the system's function.

Lee, J. D., B. F. Gore, and J. L. Campbell. 1999. Display alternatives for in-vehicle warning and sign information: message style, location, and modality. Transportation Human Factors 1:347-375.

Lee et al. evaluated message style, the physical grouping or location, and visual messages of in-vehicle warning systems to identify how message characteristics affect driving safety and compliance. They observed the actions of human test subjects presented with various warning system stimuli while operating a driving simulator. Their results suggest that command messages, as compared to notification style messages, promote greater compliance but may reduce safety. In-vehicle messages presented without redundant roadway signs displaying a similar message led to lower levels of safety.

Newhouse, N. 2003. The Wildlife Protection System: early successes and challenges using infrared technology to detect deer, warn drivers, and monitor deer behavior. Pages 390-391 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University.

<u>and</u>

Kinley, T. A., N. J. Newhouse, and H. N. Page. 2003. Evaluation of the Wildlife Protection System deployed on Highway 93 in Kootenay National Park during autumn, 2003. Progress Report.

The Wildlife Protection System (WPS) used infrared cameras to detect wildlife approaching roadways, which triggered flashing signs to warn drivers in Kootenay National Park, British Columbia. Technical difficulties prevented the system from being fully operational during the first test season in 2002, therefore, they were unable to evaluate the effectiveness of the WPS in reducing deer-vehicle collisions or the speed response of drivers to warnings produced by the WPS in 2002. During that year, however, Newhouse did use the WPS to document wildlife behavior near highways using 24-h infrared video footage. Deer activity was greatest at night, intermediate in the evening, and lowest during daytime hours. During midday, deer reacted to vehicles more often with behaviors of concern as displayed by higher rates of approaches to the highway and crossing in front of cars. During summer and fall 2003, the WPS was deployed again and its performance and ability to reduce driver speeds was evaluated. They found that driving speeds were about 6 to 9 km/hour lower within the test section than the rest of the park when the lights were not flashing. They attributed this to the presence of the equipment, signs, and radar guns associated with the WPS. When lights were flashing, speeds were reduced 10 to

21 km/hour. The WPS worked best on cool nights with an 89% proper operation rate, and it detected animals at distances >1 km. On warm days, the WPS operated most poorly, functioning properly only 25% of the time. Major maintenance problems with the WPS were attributed to power supply being unreliable and inconsistent data logging by the system. They indicated that most power supply problems could be eliminated in locations where power could be accessed from power lines, rather than be generated on-site.

Pojar, T. M., T. C. Reseigh, and D. F. Reed. 1971. Lighted deer crossing signs and vehicular speed. U.S. Department of Transportation Federal Highway Administration Interim Report No. 1478.

and

Pojar, T. M., T. C. Reseigh, and D. F. Reed. 1972. Deer crossing signs may prove valuable in reducing accidents and animal deaths. Highway Research News 46:20-23.

and

Reed, D. F., T. N. Woodard, and T. D. Beck. 1979. Regional deer-vehicle accident research. U.S. Department of Transportation, Federal Highway Administration Final Report No. FHWA-CO-79-11.

This study evaluated the effect of two types of deer-crossing signs on vehicle speeds on a four-lane Colorado highway. Sign type one had a reflective yellow, diamond-shaped background with the message “DEER XING” formed by lighted, neon tubing covered with a 0.64-cm thickness sheet of plexiglass. Sign type two had a reflective yellow background with four deer silhouettes formed with neon tubing. The deer figures were lighted in sequence from right to left to mimic a running deer. Below the animated portion of the sign, the message “DEER XING” was displayed in black letters on a rectangular, reflective yellow background. They used an automatic vehicle speed recorder to monitor traffic speeds during 16-day control periods during which each sign was turned away from passing motorists and during a 28-day test period with sign type one turned toward traffic and a four-day test period with sign type two turned toward motorists. During test periods, they activated each sign from 6:30 PM to 10:00 PM. Average vehicle speed during the control period was 87.7 km/hour. Whereas, during the test phases, average vehicle speed was reduced to 85.34 km/hour during sign type one activation, and 83.02 km/hour when sign type two was activated.

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

Pojar et al. compared rates of deer crossings per deer-vehicle collision during periods when lighted, deer-crossing signs were alternately activated and deactivated on State Highway 82 in Colorado and detected no difference in ratios during the two periods. They also monitored traffic speeds pre- and post-placement of three deer carcasses on the highway with the signs alternately activated and deactivated. With carcasses in place, mean vehicle speed dropped 10.09 km/hour when the signs were activated as compared to a reduction of 12.63 km/hour when signs were deactivated. Although motorists apparently responded to the signs by reducing speeds, this awareness was not sufficient to affect the deer crossings per kill ratio.

ALTERNATIVE MITIGATION STRATEGIES

No "alternative strategy" has proven effective in reducing vehicle collisions with white-tailed deer. Intercept feeding for migratory mule deer proved marginally effective, however, successful adaptation of this technique to white-tailed deer in the eastern U.S. is unlikely. Mr.

Alfred Williams, a citizen motorist in Georgia, suggested a novel technique where he drives over center lane reflective markers to deter deer from entering his lane of traffic. Although Mr. Williams' technique has not been scientifically investigated, it is an excellent example of how hope may exist for developing innovative techniques to reduce deer-vehicle collisions.

<u>Alternative Mitigation Strategies – Annotated Bibliography</u>

Graves, H. B., and E. D. Bellis. 1978. The effectiveness of deer flagging models as deterrents to deer entering highway rights-of-way. Institute for Research on Land and Water Resources, Pennsylvania State University, University Park, Pennsylvania, USA.

Graves and Bellis tested the effectiveness of placing rear-view silhouette models of deer with raised tails near highway fence openings in reducing deer crossings. Models consisted of painted or unpainted plyboard cutouts with either a painted tail or an actual deer tail taken from a road-killed deer. They monitored deer use of control and treatment (with silhouettes in use) areas by spotlighting at night from vehicles and by inspecting fence openings for deer tracks or deer hair. They deemed all models as ineffective for deterring deer that gained access to the highway right-of-way through fence openings.

Reed, D. F., T. N. Woodard, and T. D. Beck. 1977. Highway lighting to prevent deer-auto accidents. Colorado Division of Highways Final Report No. CDOH-P&R-R-77-5.

<u>and</u>

Reed, D. F., T. N. Woodard, and T. D. Beck. 1979. Regional deer-vehicle accident research. U.S. Department of Transportation, Federal Highway Administration Final Report No. FHWA-CO-79-11.

and

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

This study evaluated whether highway lighting effectively reduced deer-vehicle collisions on State Highway 82 in Colorado. Highway lighting was turned on and off for one-week periods. Deer-vehicle collisions, vehicle speeds, and deer crossing rates within the section of roadway were monitored daily. They detected no differences in the ratio of deer crossings per deer-vehicle collision, deer-crossing sites, or average vehicle speeds among periods when lights were on or off. However, during one evening when a deer simulation was placed in the emergency lane and lights were on, motorists significantly reduced their speed.

Williams, A. 2004. Email communication with E. Woodall, Georgia Department of Transportation, about driving over highway markers to deter deer from approaching the roadway.

Alfred Williams, a citizen motorist, reported that by driving over highway markers (reflectors partially implanted in the roadway surface) on the left of his driving lanes, he effectively deterred deer from entering the roadway. He further explained that when he drives over the markers deer always take flight away from the road rather than across it. On State Highway 119 between Stilson and Guyson, Georgia, Williams hit eight deer in eight years of driving before using the markers as deer deterrent devices. But, during four years while using the tactic, he did not hit any deer. Williams suggested placing two or three reflectors in a cluster offset to the right of the normal wheel contact area so motorists could choose to drive over the markers if desired when deer are present in the right-of-way.

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

Wood and Wolfe tested the efficacy of intercept feeding in reducing deer-vehicle collisions by diverting mule deer activity away from Utah highways. They established treatment (feed) and control (no feed) sections equal in distance and separated by unmanipulated buffer zones along three 20.8-km to 24-km sections of interstate highway. In each treatment and control zone, they selected four feeding stations ranging from 0.4-km to 1.2-km from the highway. Feed consisted of alfalfa hay, apple mash, and pelleted deer rations. In one area they replenished feed two out of three days. In a second area, they replenished feed one out of three days, and in the last area they replenished feed daily. Although the number of roadkilled deer was greater in the control sections for the first of the two experiment years, the difference was not statistically significant. During the second experiment year when the treatment and control sections were reversed, they observed significantly fewer deer-vehicle collisions in two of three test sections. Wood and Wolfe also conducted spotlight counts of deer adjacent to the test sections of roadway. They observed more deer in control zones during both years. The authors concluded that intercept feeding may reduce deer-vehicle collisions by <50% and cautioned that more subtle costs of deer feeding programs should be considered since deer may become dependent on supplemental food and be attracted to roadside areas.

TIME AND LOCATION OF DEER-VEHICLE COLLISIONS

Most research indicates that peaks in deer-vehicle collision rates occur late in the evening, at night, and in the early morning on a diurnal basis, and seasonally in the spring and fall. Modern analyses of deer-vehicle collision sites typically involve Global Information

Systems (GIS) technology combined with regression modeling to identify areas likely to experience an elevated deer-vehicle collision rate. GIS modeling also is used to select areas for implementation of mitigation strategies based on landscape and economic feasibility along with many other criteria.

Time and Location of Deer-vehicle collisions – Annotated Bibliography

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

Allen and McCullough analyzed information from police reports on 2,566 deer-vehicle collisions occurring in 1966 and 1967 to identify the time, location, and characteristics of traffic and deer that were related to collisions. Most accidents occurred at dawn, dusk, or after dark with peaks at sunrise and 2 hours after sunset. Accidents were highest on weekends when evening traffic was greatest. A seasonal peak in collision rates occurred in November and a lesser seasonal peak occurred in May. The deer was killed in 92% of the collisions, and < 4% resulted in human injury.

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.

Bashore et al. analyzed 19 habitat variables thought to influence numbers of deer-vehicle collisions along Pennsylvania two-lane highways. They used the information to develop a statistical model to predict probabilities of sections of highways of being high deer kill sites. They collected information on habitat characteristics at high kill sites and low kill control sites using maps and field observation. In the model, two variables (in-line visibility along the roadway and non-wooded areas) increased the probability of a section of highway being a high kill site. Seven variables (residences, commercial buildings, other buildings, shortest visibility, speed limit, distance to woodland, and fencing) decreased this probability. Removal of the variables speed limit and other buildings did not significantly change the model. The model showed strong discrimination between high kill and low kill sections of highway. Bashore et al. suggested that fencing was the cheapest and most effective strategy for preventing deer-vehicle collisions along short sections of highway.

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

Along a 12.9-km stretch of Interstate 80 in central Pennsylvania, Bellis and Graves monitored the distribution of 286 deer-vehicle collisions and the sex and age of individual deer killed over a 14 month period beginning two months after the first opening of the highway to traffic. They observed no difference in the sex of fawns and yearling deer killed, however many more adult females were killed than adult males. The number of deer killed per month was strongly correlated with the number observed grazing in the planted right-of-way. Mortality was highest in fall and spring. They suggested the construction of continuous fences close to the highway to allow deer access to the right-of-way and prevent end runs.

Bellis, E. D., H. B. Graves, B. T. Carbaugh, and J. P. Vaughan. 1971. Behavior, ecology, and mortality of white-tailed deer along a Pennsylvania interstate highway. The Pennsylvania State University Institute for Research on Land and Water Resources Research Publication No. 71.

<u>and</u>

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

The purpose of this study was to provide baseline information on deer/highway relationships and to serve as a resource for future projects aimed at reducing deer-vehicle collisions. They conducted nighttime observations of white-tailed deer by spotlighting along Interstate Highway 80 in central Pennsylvania. They observed over 6,500 deer along a 12.9-km section of highway in a forested region and along a 12.4-km section of highway in an agricultural region. They classified each deer sighted by location, age, sex, and behavior. Sex and age classification of deer was undetermined for nearly 90% of sightings. They observed most deer at night, and peaks in deer movements occurred at dawn and dusk. In the agricultural area, they observed most deer in crop fields, whereas a greater proportion of deer sightings in the forested areas were in the right-of-way. Seasonal peaks in deer sightings occurred during March-May and a larger peak during October-December. They observed no relationship between the number of deer sighted and weather variables or traffic volume.

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

Case analyzed seven years of data on roadkilled wildlife obtained from the Nebraska Department of Roads emergency service logs for a 732-km stretch of Interstate Highway 80 to identify trends in roadkill rates relative to month, year, average traffic speed, and average daily traffic volume. Data on nine species of wildlife were included in analyses including: ring-necked pheasant, cottontail rabbit, raccoon, skunk, opossum, white-tailed deer, coyote, badger, and muskrat. Roadkill rates peaked in May and October, likely due to breeding and dispersal activities of the wildlife species involved. Annual road-kill rates were correlated with average vehicle speed.

Craighead, A. C., F. L. Craighead, and E. A. Roberts. 2001. Bozeman Pass wildlife linkage and highway safety study. Pages 405-422 *in* Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University.

Craighead et al. developed Geographic Information Systems (GIS) models to determine potential sites for wildlife crossing structures on Interstate 90 in southcentral Montana. They compiled information on carnivore (black bear, mountain lion, gray wolf, raccoons, and red fox) and ungulate (elk, moose, mule deer, and white-tailed deer) movements relative to the roadway using road-kill data, track surveys, and remote-sensing cameras. That information was integrated with GIS data on species-specific habitat suitability and complexity; and road and building densities to construct least-cost path corridor models for placement of wildlife crossing structures.

Enderle, D. I., and P. A. Tappe. 2004. Site level factors contributing to deer-vehicle collisions on Arkansas highways. Proceedings of the 27th Annual Southeast Deer Study Group.

Enderle and Tappe compared site-level factors of 3,170 deer-vehicle collision sites to an equal number of randomly selected locations on state and federal highways in Arkansas. They used logistic regression to develop and test a statewide model and six Arkansas ecoregion models to identify areas at high-risk for deer-vehicle collisions on those highways. Based on test data, the statewide model correctly classified 63% of known collision locations. Ecoregion models correctly classified 56-70% of known collision sites. Five factors were selected for inclusion in all models, including: (1) presence and amount of water, (2) diverse association of land cover types, (3) amount and patch density of urban area within 1,200 m, (4) coniferous forest patch density and deciduous forest patch size and irregularity, and (5) pasture edge density within 1,200 m.

Farrell, M. C., and P. A. Tappe. 2003. A multivariate analysis of county-level factors that contribute to deer-vehicle collisions in Arkansas. Proceedings of The Wildlife Society Annual Conference 10:117.

Farrell and Tappe used a multivariate statistical approach to examine the influence of county-level factors on the number of reported deer-vehicle collisions in Arkansas counties during 1998-2001. They examined factors including human and deer population densities, urban growth, numerous roadway characteristics, daily traffic counts, timber harvests, and land composition and spatial characteristics. Roadway features (specific features not described), level of urbanization, and human population densities appeared to have greater influence of deer-vehicle accident occurrence than deer densities or landscape characteristics.

Finder, R. A., J. L. Roseberry, and A. Woolf. 1999. Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. Landscape and Urban Planning 44:77-85.

Finder et al. used remotely sensed data to determine habitat characteristics associated with areas of high incidences of deer-vehicle collisions. Around high accident road segments ($\geq$15 accidents from 1989-1993) and randomly selected control sites, they measured topographic features and highway construction variables within a 0.8-km radius considered conducive to deer-vehicle collisions. A logistic regression model predicted that greater distance to forest cover decreased the probability of a road segment being a high deer-vehicle collision site. The presence of adjacent gullies, riparian travel corridors crossing the road, and public recreational land within the 0.8-km radius of the site increased this probability. A model using only landscape metrics derived from satellite imagery predicted that greater landscape diversity and shorter distances between nearby forest patches increased the probability of a site being a high deer-vehicle collision site. Finder et al. suggested that remote sensing and geographic information systems may be used to implement proactive management strategies to reduce the likelihood of deer-vehicle accidents.

Grist, R. R., S. K. Williams, and E. Finnen. 1999. Development of a methodology for determining optimum locations for wildlife crossings on state highways using a geographic information systems approach with application to Key deer on Big Pine Key, Florida. Final Report, U.S. Department of Transportation Federal Highway Administration/Florida Department of Transportation.

Grist et al. used a GIS model to identify optimum areas for wildlife crossing structures to reduce vehicle collisions involving endangered Florida Key deer. They used a global positioning system to collect location information on road-kill sites, visible wildlife trails, fences, buildings, right-of-way habitat, and areas with road grade separation ideal for installation of crossing structures. The model integrated this information with data on property ownership, landuse, and property value to select potential wildlife corridors based on cost and logistic feasibility.

Hansen, L. A., K. D. Bennett, S. R. Sherwood, C. B. Bare, and J. R. Biggs. 2003. Road-crossing behavior of mule deer in the wildland-urban interface. Proceedings of The Wildlife Society Annual Conference 10:137.

Hansen et al. fitted seven adult mule deer (four male, three female) with Global Positioning System collars. They retrieved locations from three collars with 3,900-4,900 locations stored in each. They identified 817 road-crossing locations, of which 59.6% were across local residential roads and 21.9% were across collector roads.

Hubbard, M. W., B. J. Danielson, and R. A. Schmitz. 2000. Factors influencing the location of deer-vehicle accidents in Iowa. Journal of Wildlife Management 64:707-713.

Hubbard et al. examined the influence of landuse patterns and highway characteristics on 32,296 deer-vehicle collision sites on federally and state maintained highways within Iowa during 1990-1997. They used Geographic Information Systems to collect spatial information on 2.59-km^2 plots centered on 1,284 randomly selected milepost locations. Stepwise logistic regression produced a six-variable model that included four landscape variables, the number of bridges, and the number of lanes of traffic. Over 25% of deer-vehicle collision sites occurred at 3.4% of all mileposts in Iowa. Ninety-seven percent of milepost plots with greater than or equal to four bridges experienced high rates of deer-vehicle collisions ($\geq$14 deer-vehicle collisions). The logistic model correctly classified 63.3% of 245 sites in a validation data set. Their results suggest that mitigation efforts may be concentrated on areas with a high number of bridges.

Nielson, C. K., R. G. Anderson, M. D. Grund. 2003. Landscape influences on deer-vehicle accident areas in an urban environment. Journal of Wildlife Management 67:46-51.

Nielson et al. used remotely sensed data, multivariate statistics, and a geographic information system to quantify landscape factors associated with deer-vehicle accidents in two suburbs of Minneapolis, Minnesota. They classified deer-vehicle accident sites as those 0.5-km road sections with greater than or equal to two collisions involving deer and control areas where zero or one deer-vehicle collision occurred within the 0.5-km section. They initially considered 66 variables, but the most important two variables were number of public land patches and number of buildings. Using a logistic regression model containing these variables, they correctly classified 31 of 40 areas not used for model building and only used for testing purposes. Nielson et al. suggested that managers of public lands should alter deer habitat to minimize deer-vehicle collisions by reducing forest cover and shrubby areas near public roads.

Premo, D. B., and E. I. Rogers. 2001. Creating an urban deer-vehicle accident management plan using information from a town's GIS project. Pages 549-555 *in* Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University.

Premo and Rogers described how the suburban/urban community of Amherst, New York used an GIS approach to compile and analyze information on deer population estimates, deer-vehicle collision locations, and land use patterns. The information was used to direct lethal deer control efforts at areas of deer-vehicle collision "hotspots", and to formulate an adaptive deer-vehicle accident management plan. The multi-faceted management plan included modification of driver behavior, redirection of deer movements, and periodic deer population control.

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

Reilly and Green reported the trend in deer-vehicle accidents near a wintering area for white-tailed deer in upper Michigan over a 13-year period pre- and post-construction of Interstate 75 through the area in 1963. Post-construction of the interstate in 1964, highway deer kills increased by about 500% over the average kill rate of the previous four years. The highway mortality rate decreased slightly through 1967 and then fluctuated an average of twice the pre-construction yearly mortality estimate. Reilly and Green also reported that deer discontinued winter yarding on the side of the highway opposite their migration route, perhaps because the highway presented a barrier or animals that yarded in that area pre-construction of the highway were killed attempting crossings.

HUMAN DIMENSIONS ASSOCIATED WITH DEER-VEHICLE COLLISIONS

The general public greatly values deer as a public resource. Surveys show, however, that public opinion about deer management and deer-vehicle collision mitigation is affected significantly by human perception of personal risk and cost of implementation. Human dimensions researchers suggest that professionals involved with wildlife management and roadway management should combine public risk-assessment data with biological data to make decisions about alternative management strategies.

Human Dimensions Associated with Deer-vehicle Collisions – Annotated Bibliography

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

Conover used information from scientific literature to calculate a net value for deer in the U.S. at >$12 billion. This figure resulted from subtracting >$2 billion in negative monetary values ($1 billion in car damages + >$100 million in crop damages + $750 million in damage to the timber industry + >$250 million in damage to metropolitan households) from the >$14 billion in recreational value (expenses by recreationists + consumer surplus). Conover excluded from this analysis the "value" of human life and suffering resulting from deer-vehicle accidents and Lyme disease and the intangible values of deer. Conover hypothesized that as deer populations increase, the negative monetary values of deer will increase at a faster rate than the deer population. Further, as deer populations approach biological carrying capacity, Conover predicted that the number of deer-vehicle collisions would increase exponentially because deer would be forced to increase their home ranges and movements in search of forage. Conover concluded that the goal of deer management should be to keep deer populations at the point where the net positive benefit of deer is highest.

Drake, D., D. Derr, M. Hartley, and P. Maas. 2003. Suburban residents' perceptions about deer and deer management. Proceedings of The Wildlife Society Annual Conference 10:110.

Drake et al. conducted a telephone survey of 500 randomly chosen adults from New Jersey to assess suburban residents' attitudes and opinions of, and experiences with deer and deer management; and to quantify impacts from deer in suburban areas. Despite 95% of respondents expressing a positive attitude toward deer, 50% perceived that there were too many deer in New Jersey. Seventy-eight percent of respondents had a negative experience with deer (e.g. collision, landscape damage) with damage cost estimates ranging from \$50 to over \$4,000. Although 57% of respondents felt that deer control measures were necessary, 60% were unaware of current deer management options. Drake et al. concluded that public education of deer management should be heightened.

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

Hansen determined the average cost of deer-vehicle accidents in Michigan during 1978 based on the responses of 234 completed mail questionnaires sent to a systematic sample of Michigan drivers that had been involved in deer-vehicle accidents reported to Michigan State Police. In 1978, the average cost of a deer-vehicle accident in Michigan was \$648 for property damage, injury, and loss of life with an average damage to vehicle cost of \$569 including repair, substitute automobile costs, and towing.

Johnson, S. W. 2003. Determining criteria to evaluate mitigation measures to reduce wildlife-vehicle collisions: Teton County, Wyoming. Pages 654-656 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University.

Johnson interviewed 20 experts in the fields of transportation, planning, engineering, environmental services, project development, civil engineering, wildlife biology and management, and citizen transportation groups to compile criteria for evaluating mitigation measures for reducing wildlife-vehicle collisions in Teton County, Wyoming. Of 10 broad categories of criteria, the six most frequently mentioned in order of most mentioned to least mentioned included: economic possibility (e.g. cost, cost-benefit), technical feasibility (e.g. engineering constraints, land ownership constraints), political viability (e.g. compliance with laws, publicly acceptable), measurable results (e.g. technique must allow evaluation, new techniques should be tested), effectiveness (ultimate goal is to reduce accidents), and ungulate biology (e.g. strategy must not compromise integrity of habitat, must allow ungulates freedom of movement).

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

Stout hypothesized that public preference for deer population levels are influenced in part by perceptions of risk from deer-vehicle accidents. They sent a self-administered mail-back questionnaire to a systematically selected sample of 650 people drawn from a Tomkins County, New York telephone directory. They developed survey questions to study an individual's perception of risk from two viewpoints: (1) a personal assessment of his or her chance of being in a deer-vehicle collision; and (2) a societal assessment of the severity, probability, and acceptability of deer-vehicle collisions in general. Of 397 useable responses, 91% of respondents claimed to enjoy deer to some extent, and 15% hunted deer. Most (88%) were aware of deer-vehicle accidents in the county usually through personal observation of an accident event, 28% had been involved in a deer-vehicle accident, and the most frequent deer-related concerns (83%) involved deer-vehicle collisions. Despite their awareness of deer-vehicle collisions, about half (49%) of respondents preferred to maintain deer population levels at current levels, 37% wanted a decrease, and 14% wanted an increase. Stout et al. suggested that wildlife professionals should combine public risk-assessment data with biological data to make decisions about alternative management strategies.

Schwabe, K. A., and P. W. Schuhmann. 2002. Deer-vehicle collisions and deer value: an analysis of competing literatures. Wildlife Society Bulletin 30:609-615.

Schwabe and Schuhmann surveyed the literature related to the cost of deer-vehicle collisions. They reported a value range of $23 million to nearly $1 billion, depending on the calculation method used, for the deer-fatality component of deer-vehicle collisions in the U.S. In literature related to deer-vehicle collisions, estimates of single deer values range from $671 to $1,468, whereas values estimated using nonmarket valuation techniques range from $35 to $209. They concluded that the proper measure to use when estimating loss to hunters from deer mortalities related to collisions is the consumer surplus or net Willingness to Pay estimate.

West, B. C., J. A. Parkhurst, P. F. Scanlon, and W. M. Knox. 2000. Vehicle/deer collisions in Virginia: implications for management. Pages 22-23 *in* T. A. Messmer and B. C. West, editors. Proceedings of the 7th Annual Meeting of The Wildlife Society.

West et al. surveyed 732 Virginia landowners in 1996 to determine the occurrence and severity of deer-vehicle collisions and to evaluate what impact they have on the attitudes of Virginia motorists. Overall, 9.2% of respondents reported hitting a deer in 1995, and of those, 79.1% were involved in only one deer-vehicle collision. Only 3.1% of respondents involved in a deer-vehicle collision reported that they or one of their passengers was injured, and 68.8% did not report the incident(s) to law enforcement. The average cost of vehicle repairs resulting from a single collision was $1,386 with a range of $100 to $4,700. Nearly 53% of all respondents rated the risk level of experiencing a deer-vehicle collision in their county as moderate.

DEER HEARING

Information on white-tailed deer hearing abilities and their response to sound frightening devices is limited. Previous research on deer hearing was preliminary in nature, and investigations of the efficacy of sound deterrents were of poor experimental design. Studies have indicated that deer likely have hearing abilities similar to humans, thus suggesting that current sound deterrent devices are probably not within the hearing thresholds of deer and have no promise of being effective.

Deer Hearing – Annotated Bibliography

Belant, J. L., T. W. Seamans, and L. A. Tyson. 1998. Evaluation of electronic frightening devices as white-tailed deer deterrents. Wildlife Society Bulletin 26:264-268.

and

Belant, J. L., T. W. Seamans, and L. A. Tyson. 1998. Evaluation of electronic frightening devices as white-tailed deer deterrents. Proceedings of the Vertebrate Pest Conference 18:107-110.

Belant et al. tested three ultrasonic devices; the motion-activated Yard Guard, the motion-activated Usonic Sentry, and Electronic Guard; in attempts to develop a technique for reducing deer depredation of agricultural crops, winter livestock food supplies, and ornamental plantings. The Yard Guard was evaluated at the medium frequency setting (20 to 28 kHz, 114 dB at 1 m), which was emitted for about 7 seconds at a time. The Usonic Sentry was evaluated at 23 to 35 kHz with sound pressure of 160 dB at 1 m, and sound was emitted for 8 to 28 seconds when activated. Electronic Guards were equipped with a white strobe light (70,000 candlepower, flash rate = 60/minute) and a 1.4 kHz modulating (15 to 20 modulations/minute) siren with 116 dB output at 1 m. Electronic Guards also had a photocell, which allowed operation only during night. During two 4-week experiments, they monitored deer use (number of intrusions into plot and corn consumption) at eight feeding stations in a 2,200 ha fenced facility with a high deer density ($\geq$38 deer/km^2). During experiments, one of the devices was positioned at each of four sites. The mean daily number of deer intrusions at feeding stations during treatment was greater than or equal to the mean daily number of deer intrusions during pre- or post-treatment. Corn consumption declined only at stations with Usonic Sentrys for one week. They concluded that the devices were ineffective at deterring deer from preferred feeding stations.

Bender, H. 2003. Deterrence of kangaroos from agricultural areas using ultrasonic frequencies: efficacy of a commercial device. Wildlife Society Bulletin 31:1037-1046.

Bender conducted laboratory and field evaluations of the ROO-Guard, an ultrasonic device manufactured by the Shu-Roo company and designed to protect agricultural areas from kangaroo depredation. Bender's laboratory trials indicated that the ROO-Guard had only a small component of ultrasonic frequencies. The device did not alter the behavior of captive eastern gray kangaroos or red kangaroos in any way. Bender found that the ROO-Guard did not reduce the density of free-ranging eastern gray kangaroos at sites where the device was operating as compared to control sites, and she observed no change in kangaroo density with distance from the device.

Bomford, M., and P. H. O'Brien. 1990. Sonic deterrents in animal damage control: a review of device tests and effectiveness. Wildlife Society Bulletin 18:411-422.

Bomford and O'Brien reviewed literature related to the mechanisms by which sonic devices may affect animals, and evaluations of sonic devices. They concluded that although numerous devices had been developed and assessed, many reported tests were inconclusive. They recommended that future tests would be improved by: adequate experimental control and replication, avoidance of pseudoreplication (occurs when treatments are not replicated or replicates are not statistically independent), appropriate measures of device effect, and quantitative description of the sound produced.

Flydal, K., and P. S. Enger. 2001. Hearing in reindeer (*Rangifer tarandus*). Journal of Comparative Physiology 187:265-269.

Flydal and Enger determined audiograms for two yearling male reindeer using conditioned suppression/avoidance procedure. Trials were started as the animal drank from a metal bowl of water while pure tone signals were played at random intervals and followed by an electric shock in the bowl. By breaking contact with the bowl at sound signals, the animal avoided the shock and indicated that it heard the sound. They found that the reindeer detected sounds at intensities of 60 dB or less from 70 Hz to 38 kHz. The frequency range of best sensitivity was relatively flat from 1 kHz to 16 kHz, with best sensitivity of 3 dB at 8 kHz.

Gilsdorf, J. M., S. E. Hygnstrom, K. C. VerCauteren, G. M. Clements, E. E. Blankenship, and R. M. Engeman. 2004. Evaluation of a deer-activated bio-acoustic frightening device for reducing deer damage in corn fields. Wildlife Society Bulletin 32:515-523.

Gilsdorf et al. developed a bio-acoustic frightening device to reduce deer damage to agricultural crops. The device included an infrared detection system used to detect the presence of deer entering the edge of a cornfield, which then activated an audio alarm system designed to broadcast deer distress calls. They recorded the distress calls while handling deer live-captured in netted cage traps within the study area at the DeSoto National Wildlife Refuge, Nebraska. They placed two frightening devices on the perimeter of each experimental field adjacent to wooded areas where the highest crop damage was expected to occur. They conducted trials starting at the onset of the silk-tasseling stage of corn growth and until corn maturity. They used indices of track counts, corn yields, crop damage assessments, and use-areas of radiomarked deer to evaluate the efficacy of the devices in experimental fields versus in control fields. They concluded that the bio-acoustic device, which cost about $600 per unit, was not effective in protecting corn fields.

Gilsdorf, J. M., S. E. Hygnstrom, K. C. VerCauteren, E. E. Blankenship, and R. M. Engeman. 2004. Propane exploders and Electronic Guards were ineffective at reducing deer damage in corn fields. Wildlife Society Bulletin 32:524-531.

Gilsdorf evaluated the effectiveness of propane exploders and Electronic Guards for reducing deer damage in corn fields during the silk-tasseling stage of corn growth at the DeSoto National Wildlife Refuge (DNWR) and Loess Hills State Forest (LHSF), Nebraska. Gilsdorf et al. connected propane exploders to a bottle of propane and set the units to discharge at 15 minute intervals throughout the night at a sound level of 130 dB (as measured at 75 m). Electronic Guards consisted of a photo cell (to activate the device at sunset and to shut it off at sunrise), timer, flashing white strobe light (70,000 candlepower, flash rate = 60/minute) and a 1.4-kHz modulating siren (15-20 modulations/minute, 116-dB output at 1 m). They set the Electronic Guard to randomly activate sound for 7-10 seconds at 6-7 minute intervals throughout the night. They selected four groups of three test fields each on DNWF and LHSF. Each field was about 9 ha and was greater than or equal to 1 km from the other fields used in the experiment. They randomly assigned treatment (experimental = either two propane exploders or two Electronic Guards/field, control = no devices in the field). They used indices of track counts, corn yields, crop damage assessments, and use-areas of radiomarked deer to evaluate the efficacy of the devices in experimental fields versus in control fields. They concluded that neither propane exploders nor Electronic Guards were effective in reducing deer damage to corn fields.

Krausman, P. R., L. K. Harris, C. L. Blasch, K. K. Koenen, and J. Francine. 2004. Effects of military operations on behavior and hearing of endangered Sonoran pronghorn. Wildlife Monographs 157.

Krausman et al. evaluated whether routine military activities (airplane noise, noise from ordinance delivery, and ground-based activity) on the Barry M. Goldwater Range, Arizona affected the behavior of the endangered Sonoran pronghorn. They compared behavior and activity of Sonoran pronghorn to other pronghorn in an adjacent population, which were not regularly exposed to military activity. They contrasted the hearing of pronghorns not in the Sonoran population and that were not exposed to regular military activity (they could not test Sonoran pronghorn because of their endangered status) to two different groups of desert mule deer that were and were not exposed to sound pressure levels from military activity by testing hearing thresholds using auditory brainstem responses (ABR). ABRs are electrical potentials generated by the brainstem when the ear is stimulated by sound. Krausman et al. recorded mean thresholds at intensity levels up to 90 dB and obtained responses from 0.5 kHz to 8 kHz for the pronghorn and mule deer, and found no difference in the ABR thresholds between the control and exposed animals. They concluded that military activity had no apparent effect on pronghorn auditory characteristics and only a marginal influence on their behavior.

Risenhoover, K. L., J. F. Hunter, R. A. Jacobson, and G. W. Stout. Year Unknown. Hearing range in white-tailed deer. Abstract for The Wildlife Society Texas Chapter Meeting.

Risenhoover et al. determined audiogram hearing thresholds for five sedated white-tailed deer by recording brainstem evoked potentials in response to stimuli consisting of 45-millisecond pure-tone pips delivered using headphones held against the ears. They recorded evoked potentials at intensity levels up to 85 dB in a frequency range of 0.5 to 16 kHz. At intensity levels of 95 dB a response was obtained up to 16 kHz. The range of greatest hearing sensitivity was between 1-8 kHz with a marked peak at 4 kHz.

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

Romin and Dalton tested two models of deer warning whistles, Game Tracker's Game Saver and the Sav-a-life Deer Alert. They separately tested each device on free-ranging mule deer along a dirt road at a wildlife management area in Carbon County, Utah, on which 0.28 deer-vehicle collisions/km occurred annually. Testing was done in two passes with the research vehicle traveling at 65 km/hour. In the first pass, they recorded distance of deer from the road and deer reaction to the passing vehicle without activating the whistles. Immediately following, they traveled greater than or equal to 0.8 km past the deer group, activated the whistles, turned the vehicle around and passed the group again to record their distance and reaction. In observations of 150 deer groups that were within 100 m of the road, they recorded 152 responses and detected no difference between responses with or without either type of whistle.

Scheifele, P. M., D. G. Browning, and L. M. Collins-Scheifele. 2003. Analysis and effectiveness of deer whistles for motor vehicles: frequencies, levels, and animal threshold responses. Acoustics Research Letters Online 4:71-76.

Scheifele et al. recorded the frequencies and intensities generated by six deer whistles (no make or model specified, the authors only distinguished the devices by referring to "closed end" and "open end" designs, but did not describe these classifications). They made laboratory recordings with a digital audio tape recorder while forcing air directly into the mouth of each whistle until a strong sound was emitted. In road tests, they mounted "the two loudest whistle pairs" on the bumpers of two separate vehicles. They recorded ambient noise levels and sounds from the vehicles mounted with whistles during 10 duplicate runs at speeds of 48 km/hour, 56 km/hour, 64 km/hour, and 88 km/hour. Scheifele determined the primary frequency of operation for the "closed-end" whistles to be 3.3 kHz, and 12 kHz for the "open-end" whistles. Scheifele used information provided by Risenhoover et al. (Texas A&M University) to compare white-tailed deer hearing thresholds to the effective sound emission of the deer whistles tested. However, they failed to make any definitive evaluation of the effectiveness of the whistles.

Weisenberger, M. E., P. R. Krausman, M. C. Wallace, D. W. De Young, and O. E. Maughan. 1996. Effects of simulated jet aircraft noise on heart rate and behavior of desert ungulates. Journal of Wildlife Management 60:52-61.

Weisenberger et al. implanted heart rate transmitters in captive desert mule deer and mountain sheep to evaluate the effects of simulated low-altitude jet aircraft noise on their behavior and heart rate. They conducted simulated overflights one to seven times per day at noise levels between 92-112 dB during three seasons. The heart rates of the desert mule deer and mountain sheep increased related to dB levels, but returned to pre-simulation levels within 60-180 seconds. They also observed changes in animal behavior that lasted <252 seconds after simulated overflight. All animal responses decreased with increased exposure suggesting that they habituated to simulated sound levels of low-altitude aircraft.

DEER VISION

Electrophysical examination and behavioral research has established that white-tailed deer are capable of limited color vision. During the day, deer likely can discriminate in the color range of blue to yellow-green, and at night in the blue to blue-green color range. Little else is known about how white-tailed deer perceive the world. Information on their visual acuity and depth perception are lacking.

<u>Deer Vision – Annotated Bibliography</u>

Jacobs, G. H., J. F. Deegan, J. Neitz, B. P. Murphy, K. V. Miller, and R. L. Marchinton. 1994. Electrophysical measurements of spectral mechanisms in the retinas of two cervids: white-tailed deer (*Odocoileus virginianus*) and fallow deer (*Dama dama*). Journal of Comparative Physiology 174:551-557.

Jacobs et al. used electroretinogram flicker photometry to study the spectral mechanisms in the retinas of white-tailed deer and fallow deer. Both species appeared to possess a maximum rod pigment sensitivity of about 497 nm and two classes of photopic receptors. Both species also shared a common short-wavelength-sensitive cone mechanism in the region of 450-460 nm (blue). The white-tailed deer peak cone sensitivity was about 537 nm (yellow-green), and the fallow deer peak cone sensitivity was about 542 nm. They concluded that deer resemble other ungulates and many other types of mammals in having two classes of cone pigment, and, thus, the retinal basis for dichromatic color vision.

VerCauteren, K. C., and M. J. Pipas. 2003. A review of color vision in white-tailed deer. Wildlife Society Bulletin 31:684-691.

VerCauteren and Pipas reviewed and summarized literature related to white-tailed deer color vision and arrived at the following conclusions. White-tailed deer possess two types of cone mechanisms with sensitivity in the short (450-460-nm range) and medium wavelengths (maximum sensitivity of about 497 nm). During the day, it is likely that deer see colors in the range that humans would define as blue to yellow-green, and they may be able to discern longer wavelengths (red and orange) from medium wavelengths (green). At night deer perceive color in the human-defined blue to blue-green portion of the spectrum.

Witzel, D. A., M. D. Springer, and H. H. Mollenhauer. 1978. Cone and rod photoreceptors in the white-tailed deer, *Odocoileus virginianus*.

Witzel et al. established that white-tailed deer retinas are composed of rods and cones. They used histology, light microscopy, and electron microscopy on eyes taken from dead deer; and electrophysical examinations of the eyes of sedated deer to identify the presence of both rods and cones. Previous belief was that deer retinas were composed entirely of rods.

CONCLUSION AND RECOMMENDATIONS

Although many aspects of deer biology have been well studied, we lack a basic understanding of the anatomy and physiology related to the hearing and visual capabilities of deer, information which may prove integral to the invention of economically effective strategies to minimize deer-vehicle collisions. Further, our knowledge of deer behavior relative to roads is inadequate. Limiting our evaluations of deer-vehicle collision mitigation devices to comparisons of deer road-kill statistics, for example, tells little about the complex interaction of deer and motorist behavioral traits that leads to collisions. When conducting future tests, we should make detailed observations of deer behavior relative to the implementation of mitigation techniques and, when possible, also document motorist awareness and response to the strategies. Such data may be used to improve strategies during the design and planning stages rather than as a basis for critique after mitigation strategies are widely instituted or enter the manufacturing process.

At present, fences of the appropriate height may be the most effective method to exclude deer from roads. However, transportation and wildlife managers have an ethical responsibility to consider the potential ecological impacts of fencing on animal populations. Traditional fence designs may severely limit gene flow among populations separated by fenced roads. Fencing also may restrict wildlife access to resources critical to their survival. Crossing structures within fenced roadway corridors may provide partial habitat connectivity for some wildlife species, and have proven most successful when used where traditional migratory routes of mule deer, elk, and other migratory species intersect highways. However, white-tailed deer generally do not make mass seasonal migrations, and are more likely to cross roads within their home ranges on a daily basis. Over a single kilometer, a roadway may be intersected many times by the home ranges of different white-tailed deer in an area. A stark example of the crossing rate of white-tailed deer was reported in a study of deer mortality on a new Pennsylvania highway where Bellis and Graves (1971) documented an average of more than 22 road-killed deer/km over a 14-month period. Previous reports rated wildlife crossing structures as cost prohibitive for most applications. Considering the road-crossing behavior of white-tailed deer and the cost of wildlife crossing structure installation, reliance on fencing to prevent deer-vehicle accidents likely is not a feasible option.

Currently there is no simple, low-cost solution for reducing the incidence of deer-vehicle collisions. Like fencing, other devices, including wildlife warning reflectors and motorist warning systems, are used where deer regularly cross roads. Only instituting collision reduction techniques at select areas or “hotspots” will not guard against non-habitual deer road crossings, which typically occur during the peak seasons for deer-vehicle collisions (breeding and fawning). To guard against these collisions and to provide the most effective system for minimizing deer-vehicle collisions, we have three general conclusions and recommendations:

(1) Vehicle-mounted deer warning systems may have the best potential for minimizing deer-vehicle collisions; however, to date none of these systems has been designed in accordance with the senses of deer. Therefore, future research and development of vehicle-mounted deer warning systems must be based on detailed knowledge of deer vision, hearing, and behavior.

(2) Every year, motorist awareness of the danger of deer-vehicle collisions can decline over time. Therefore, agencies should develop and routinely implement education programs and/or highway warnings to enhance motorist awareness prior to and during the seasons of greatest danger for deer-vehicle collisions (breeding and fawning).

(3) Deer overabundance can increase the potential for deer-vehicle collisions. Therefore, agencies and municipalities should implement proper deer herd management programs designed to control deer abundance.