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THINKING OUTSIDE THE MARKETPLACE: A BIOLOGICALLY BASED APPROACH TO REDUCING DEER-VEHICLE COLLISIONS

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Abstract: Deer-vehicle collisions are a major concern throughout much of the World, accounting for human injury and death, damage to vehicles, and immeasurable waste of deer as a wildlife resource. Throughout the planning of our research project, we reviewed the primary literature to identify strategies with the most potential to reduce deer-vehicle collisions. Our review is available online as an annotated bibliography at: http://www.forestry.uga.edu/h/research/wildlife/devices/GADOTLiteratureReview.pdf.

Our findings indicated that most states in the U.S. have attempted to minimize deer-vehicle collisions through a variety of techniques. However, most studies have not empirically examined the efficacy of such techniques and many deer-deterrent devices were not designed with an understanding of the sensory capabilities of deer. Many previous studies also were isolated in scope or were inadequately replicated to afford statistical validity. Hence, the questions regarding efficacy of many deer deterrent devices remain largely unanswered and there still exists a need for research on mitigation strategies based on the sensory abilities of deer.

Until these research results become available, management efforts to minimize deer-vehicle collisions should focus on (1) implementing proper deer-herd management programs; (2) controlling roadside vegetation to minimize its attraction to deer and maximize visibility for motorists; (3) increasing motorist awareness of the danger associated with deer-vehicle collisions; (4) thoroughly monitoring deer-vehicle collision rates; and (5) encouraging communication and cooperation among governments, wildlife researchers, highway managers, motorists, and others involved in the issue of deer-vehicle collisions. We are conducting a research project designed to provide a more thorough understanding of the physiological processes driving white-tailed deer (*Odocoileus virginianus*) roadway behavior. Our ultimate goals are to use this knowledge to develop improved strategies designed to reduce deer-vehicle collisions.

Introduction and Critical Literature Review

Citations and a brief summary of all literature related to deer-vehicle collision reduction strategies that we reviewed are available online as an annotated bibliography at: http://www.forestry.uga.edu/h/research/wildlife/devices/GADOTLiteratureReview.pdf.

After our review of the literature, several prominent themes were evident: (1) Of the mitigation technologies previously studied, fencing of adequate height combined with the proper wildlife-crossing structures was 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 included: 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, implement successfully, 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.

Fences and wildlife-crossing structures

Roadside fencing was arguably the most-studied device implemented to reduce the incidence of deer-vehicle collisions. Most research indicated that fences were not an absolute barrier to deer and only served 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 fencing, 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 point. Although fencing is not a complete barrier to deer, its presence may severely limit the natural movements and gene flow of deer populations and other wildlife. Fencing coupled with a variety of underpasses, overpasses, road-level crosswalks, one-way gates, and other strategies were tested to allow animals to cross roadways at controlled areas along fenced highways. Crossing structures were 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.

Wildlife-warning reflectors
Studies of wildlife-warning reflectors have been based on a diversity of testing methods and various levels of scientific validity, which ultimately have resulted 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 failed to consider changes in deer densities, seasonal movements, or traffic patterns. Further, studies evaluating reflector effectiveness have been hampered by small sample sizes that limited statistical inferences on efficacy. Little is known about how deer react to reflector activation or if individual animals become habituated to the devices over time. Studies that used counts of deer carcasses along roadways to assess reflector effectiveness rarely used 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 was confounded further by the variety of reflector models tested and the distinct spectral properties of those devices.

Motorist-warning devices
Active and passive driver-warning devices were largely ineffective at reducing vehicle speeds and deer-vehicle collisions. Drivers ignored the common "deer crossing" sign, perhaps because of its overuse. Reduced vehicle speed was the most common method used for assessing warning-device effectiveness, even though this response was not the primary desired effect of warning drivers about site-specific dangers associated with wildlife crossings. No studies to date 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, was unclear despite the high cost of such devices. Research indicating that non-redundant command-type messages impact driver behavior more than notification-style messages, which 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.

Alternative mitigation strategies
No "alternative strategy" proved effective in reducing vehicle collisions with white-tailed deer. Intercept feeding for migratory mule deer (*Odocoileus hemionus*) proved marginally effective. However, successful adaptation of this technique to white-tailed deer in the eastern U.S. is unlikely. Other alternative approaches included variations of highway lighting and even placing imitations of deer with raised tails along roadways. Although not successful in reducing deer-vehicle collisions, such approaches provided evidence that deer-vehicle collision-reduction research may require a departure from typical study designs.

Time and location of deer-vehicle collisions
Most research indicated that peaks in deer-vehicle collision rates occurred 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 involved Global Information Systems (GIS) technology combined with regression modeling to identify areas likely to experience an elevated deer-vehicle collision rate. GIS modeling also was used to select areas for implementation of mitigation strategies based on landscape and economic feasibility, along with many other criteria.

Human dimensions associated with deer-vehicle collisions
The general public greatly values deer as a public resource. Surveys showed, however, that public opinion about deer management and deer-vehicle collision mitigation was affected significantly by human perception of personal risk and cost of implementation. Human-dimensions researchers suggested 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.

Deer hearing
Information on white-tailed deer hearing abilities and their response to sound-frightening devices was limited. Previous research on deer hearing was preliminary in nature and investigations of the efficacy of sound deterrents employed along roadways were of poor experimental design. Several studies indicated that deer likely have hearing abilities similar to humans, thus suggesting that "ultrasonic" sound-deterrent devices would be ineffective for deer.

Deer vision
Electrophysical examination and behavioral research 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 visually perceive the world. Information on deer visual acuity and depth perception was lacking.

Conclusions and recommendations
Although many aspects of deer biology were 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. Furthermore, 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 were most successful when used where traditional migratory routes of mule deer, elk (*Cervus elaphus*), and other migratory species intersected 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. 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, were 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.

Our Research Project

Project objectives

Based on our review of the literature, we designed our research project to accomplish the following objectives:

1. Investigate the visual physiology of white-tailed deer to determine their visual acuity, their ability to discern patterns and shapes, and to gain new insight on deer color and night vision.
2. Investigate the auditory physiology of white-tailed deer to determine the range of their hearing capabilities.
3. Determine roadway behavior of deer and test the effect of wildlife-warning reflectors and auditory deterrents in altering deer roadway behavior.
4. Use new information on deer senses and roadway behavior to improve on existing technologies and develop new strategies to reduce the incidence of deer-vehicle collisions.

Deer vision

We are utilizing a combination of laboratory techniques and behavioral testing to determine white-tailed deer visual capabilities, which were not documented previously. We are training captive-raised deer through discrimination learning to select positive visual targets in a range of spatial frequency gratings, patterns, and shapes. We are calculating visual-acuity scores based on the spatial grating of the highest frequency that the animal is able to discern. Likewise, we will reduce the size of shapes and increase the complexity of patterns to determine those which are most reliably perceived by our trained deer. We are using immunohistochemistry to label rod and cone photoreceptor cells fluorescently and staining to visualize ganglion cells in the deer retina. We are developing spatial-density maps of cells across the retina to provide better understanding of light-signal processing by the deer visual system. Using our estimates of ganglion-cell densities, we also will be able to infer deer visual-acuity limits.

Deer hearing

We are conducting auditory brainstem response testing to estimate deer-hearing capabilities. While sedated, we expose their hearing system to a range of frequencies from 250 Hz to 30,000 Hz at intensities up to 90 dB. We will analyze auditory electrical potentials evoked from the deer's brainstem to estimate the lowest threshold at which the deer's hearing system can detect sounds throughout the range of tested frequencies. Our preliminary results on 13 deer indicate that deer hearing is less sensitive than that of humans at lower frequencies. At moderate to high frequencies, deer hearing appears to be more sensitive than human hearing and may extend to at least 30,000 Hz. We are performing subsequent trials to determine the behavioral response of deer to auditory cues.

Behavioral field experiments

Our research approach to evaluate the effectiveness of deer-vehicle collision reduction techniques will consider roadway behavior of deer relative to such techniques. This experimental design differs from most other studies of similar purpose, which traditionally have used counts of deer carcasses along test sections of road. We will use a forward-looking infrared camera to monitor deer behaviors at night when negative deer-vehicle interactions are most likely to occur. We will assess deer-behavioral responses to normal vehicle traffic as compared to deer responses to vehicles when reduction techniques are activated. Our experiments will determine the effectiveness of reduction techniques currently available and will provide basic information on deer roadway behavior, which is integral to the development of effective and economically feasible strategies to minimize deer-vehicle collisions.

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