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MOTORIST RESPONSE TO A DEER-SENSING WARNING SYSTEM IN WESTERN WYOMING

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Abstract: The migratory route of the Wyoming Range mule deer (*Odocoileus hemionus*) herd is bisected by U.S. Highway 30 between Kemmerer and Cokeville, Wyoming, resulting in hundreds of deer-vehicle collisions at this site each year. We tested the effectiveness of the FLASH system, designed to detect deer presence on the highway and warn motorists by triggering flashing lights associated with a sign. We collected data on deer activity, system reliability, and vehicle speed in response to the warning signs. We also conducted a series of experimental manipulations to determine motorist response to the system with the lights flashing or not flashing and with the presence or absence of a realistic deer decoy in the road. It was found that more than 50 percent of the hits registered by the FLASH system were false hits not caused by deer, though a backup deer detection system worked well throughout the study period, with no false hits detected. Vehicles were not found to slow down significantly for the warning signs, although they did slow down in response to deer presence. During the experimental manipulations, vehicles only significantly reduced their speed (11.6 and 6.3 mph on average for passenger vehicles and tractor trailers respectively) when the deer decoy was in the crossing. Vehicles responded to the other treatments by reducing their speed by an average of less than 5 mph. The system tested may be effective in preventing deer-vehicle collisions under different traffic conditions, but is not suitable for this particular site.

Introduction

Roads cover one percent of the land area of the United States (Forman and Alexander 1998), and inevitably differing needs of motorists and wildlife result in conflict, most obviously manifested in the form of wildlife-vehicle collisions. Conservatively, it has been estimated that 500,000 deer were killed by deer-vehicle collisions in 1991 alone, and insurance companies estimate that 120 people per year die in deer-related accidents (Romin and Bissonette 1996). Many different approaches have been attempted to reduce wildlife-vehicle collisions, with varying degrees of success. Measures such as reflectors (Schaefer and Penland 1985, Waring et al. 1991, Reeve and Anderson 1993, Ujvari et al. 1998), whistles (Romin and Dalton 1992), lighting (Reed 1981), animated signs (Pojar et al. 1975) and crosswalks (Lehnert and Bissonette 1997) are largely ineffective in reducing wildlife mortality along roads. Underpasses and fencing are more consistently effective in reducing wildlife on the right of way and wildlife mortality (Ward 1982, Ludwig and Bremicker 1983, Singer and Doherty 1985, Feldhamer 1986, Hunt et al. 1989, Foster and Humphrey 1995, Yanes et al. 1995, Clevenger et al. 2000) but are not necessarily economically or logistically feasible in all areas. A system that detects deer and advises motorists of deer presence may be effective in reducing deer-vehicle collisions, but to our knowledge has not yet been tested.

In this study we evaluated the effectiveness of the Flashing Light Animal Sensing Host (FLASH) system in causing motorists to reduce their speed and thus potentially avert collisions between mule deer (*Odocoileus hemionus*) and vehicles along U.S. Highway 30 through Nugget Canyon in western Wyoming. This stretch of highway bisects the migration route of the Wyoming Range mule deer herd. Hundreds of deer-vehicle collisions occur each year between mileposts 27 and 42 as thousands of mule deer migrate between their winter and summer ranges. In 1986, the Wyoming State Legislature passed the Nugget Canyon Wildlife Migration Project Act calling for state agencies to work together in attempting to mitigate the problem of deer-vehicle collisions in this area. In compliance with this legislation, several mitigation measures have been attempted in Nugget Canyon. In 1989 a seven-mile long, eight-foot high deer-proof fence was erected with a gap for mule deer crossings at milepost 30.5. Signs warning motorists of migratory deer crossings were installed in association with the fence, but deer mortality remained high. Swareflex reflectors were evaluated but found to be ineffective in reducing deer-vehicle collisions (Reeve and Anderson 1993).

The system tested in this study operates in conjunction with the deer fence. As deer move through the gap in the fence, an infrared sensor is triggered, activating flashing lights associated with a sign that reads, "Deer on Road When Lights are Flashing." The primary objectives of this study were as follows:

1. Determine how numbers of deer crossing US 30 in Nugget Canyon vary with time of day and season
2. Assess the accuracy of the FLASH system in detecting deer and compare FLASH counts of deer to counts made by other systems
3. Evaluate the effectiveness of FLASH in causing motorists to reduce their speed approaching the deer crossing under various conditions

Study Area

The Nugget Canyon study area is located in the southwest portion of Lincoln County, Wyoming, within a major mule deer winter range complex, the Cokeville-Rock Creek (C-RC) winter range. This is one of several winter ranges used by mule deer in the Wyoming Range mule deer herd unit (Reeve and Anderson 1993).

Deer-vehicle collisions primarily occur along a 15-mile segment of U.S. Highway 30 from milepost 27 to milepost 42, which includes the area described in the Nugget Canyon Migration Project Act (milepost 27 to milepost 39.7). The Union Pacific Pocatello, Idaho, rail line parallels U.S. Highway 30 through the project area. Twin Creek, a tributary of the Bear River, flows through Nugget Canyon and is fed by other streams in north-south oriented drainages. Major ridges, including Boulder Ridge, Rock Creek Ridge, Dempsey Ridge, and Sellem Ridge, orient mule deer migration patterns so that they cross the highway during spring and fall migrations to and from their summer range to the north.

Elevations on the floor of Nugget Canyon range from 2000m at the east end to 1923m at Sage Junction. Big sagebrush (*Artemisia tridentata*) is the dominant vegetation in the area and is interspersed with mountain shrubs including Utah serviceberry (*Amelanchier utahensis*), antelope bitterbrush (*Purshia tridentata*) and snowberry (*Symphoricarpos* spp.) (Oedekoven and Lindzey 1986). Riparian willow (*Salix* spp.) is common along creek margins. Most deer on the C-RC have been observed in sagebrush-grass vegetation throughout the winter period, though mountain shrub vegetation is used by mule deer in early winter (Edberg 1990).

U.S. Highway 30 is a two-lane rural highway used heavily by tractor-trailers traveling between Interstate 80 and Utah, Idaho, and other destinations northwest of the site. Additionally, the route is frequently used by out-of-state tourists traveling to Jackson, WY, and Yellowstone National Park. Approximately 1,500 vehicles use the highway each day during the fall/winter/spring months, with most of the use occurring during daylight hours. The average speed of motorists on the highway is just under the speed limit, which is 65 mph.

Methods

Description of systems

The FLASH system and accompanying data collection systems were installed in the deer crossing in Nugget Canyon at milepost 30.5. Two different systems were used to detect deer presence in the crossing (figure 1, end of paper). The FLASH system, installed December 1, 2000, consisted of infrared sensors, which detected the body heat of animals. These sensors transmitted a signal to a receiving unit, which activated flashing lights associated with a sign to warn motorists. The signs were located to the east and west of the crossing, approximately 300m from the crossing. The signs could be turned to display one of two messages: "Attention: Migratory Deer Crossing," which was the standard message encountered by motorists when the FLASH system was not operating, or "Deer on Road when Lights are Flashing," used in association with the FLASH system. A geophone unit which detected ground vibrations caused by animals crossing at the south side of the site, paired with infrared scopes at the north and south sides of the site, was activated on October 1, 2000, and used as a back-up system for gathering data on deer crossings. Number of detections by both deer systems were recorded by an automated counter. Additionally, a video-camera system installed December 5, 2000, in conjunction with another study was used to monitor deer movement through the crossing.

Data consisting of speed, classification, and size of vehicles traveling along US 30 were collected by piezosensors located at points east and west of the crossing as well as at the crossing. The east and west piezosensors gathered speed data on vehicles before the warning sign was encountered by motorists, whereas the sensor at the crossing gathered speed data on vehicles after motorists had responded to the sign. These speed data as well as data collected by the deer detection systems were stored in a counter and downloaded remotely via modem.

Data collection

Deer activity and numbers

Our data collection period commenced on October 1, 2000, and continued until May 21, 2001. Deer activity data were collected by three different systems. The FLASH and geophone systems transmitted number of hits on the system at five-minute intervals to a data logger. Multiple hits could be registered by one deer moving back and forth through the crossing, or a single hit could be registered by multiple deer moving through the crossing simultaneously. Therefore, the data collected by the FLASH and geophone systems provided an estimate of deer activity rather than precise numbers.

The video camera system was used to estimate numbers of deer passing through the crossing. The camera was activated each time the geophone sensor was tripped and the entire area of the crossing was filmed for two minutes. Number of deer crossing the highway, date, and time of day were obtained from the videotapes. Data from the three different systems were converted into average number of hits and deer per day for each month the system was active. The geophone system collected data for the entire period, but the video camera and FLASH systems were not activated until December 4, 2000. We used these three systems to determine how deer movement varied with time of day and season.

Evaluation of FLASH and geophone system reliability

Activity on the FLASH and geophone systems was monitored via a remote link that allowed researchers to view hits on both systems as they occurred. Two-hour observations were conducted at varying times during daylight hours in conjunction with the collection of treatment data. During these observations, the crossing was monitored for deer activity, and FLASH and geophone systems were watched to determine if the deer were registering on the system. Data consisting of the number of accurately registered hits, number of false hits, and number of times deer crossed without being detected were collected. Due to a power failure in the trailer from which observations were conducted, the remote link was not used after January 23, 2001, and instead times of deer crossings were noted and later confirmed when deer crossing data was downloaded. Additionally, times of deer crossings observed outside of watch times were noted and later confirmed by examining deer crossing data.

Problems that developed with the FLASH system that came to our attention in January prompted us to examine further the number of false hits that the FLASH system was registering. Three days of deer crossing data were selected at random from each month that the system was active (December- May). We compared the number of hits on the FLASH and geophone systems during those days and computed the percentage of hits that registered on the FLASH system with no confirming hits on the geophone system. Since the geophone system was never found to register false hits, we felt justified in using it as a gauge of the accuracy of the FLASH system.

Evaluation of FLASH system effectiveness in reducing motorist speed.

The FLASH system was engaged full-time on December 8, 2000, and allowed to activate the warning signs until May 21, 2001, with the exception of times during which experimental manipulations were conducted and times during which the system was undergoing repairs. Vehicle speed data and deer crossing data were downloaded remotely during this period. Two days were chosen at random from each month, and vehicle speed data was coded according to whether or not a deer was present at the time the vehicle moved through the crossing. Differences in vehicle speeds before and after viewing the warning sign were compared between times when the sign was activated (deer present) and times when the sign was inactive (deer absent). Later in the season the FLASH system started registering numerous false hits. Consequently we also analyzed the speeds of a third category of vehicles that moved through the crossing when the sign was activated but no deer were present.

In addition to evaluation of the motorist response to the system under normal operating conditions, a series of experimental manipulations was performed in order to determine how different configurations of signs, lights, and presence or absence of deer affected vehicle speed. Consequently, we had two separate data sets: the observational data set described above in which motorist speed during normal operation of the FLASH system was assessed, and an experimental data set in which we examined motorist speed in response to manipulations of the system. The two data sets are treated separately in the results.

Vehicles were exposed to five different treatments that were switched at two-hour intervals. Each treatment was performed at four different times and two sets of four treatment blocks were conducted in each month. Change in vehicle speed was compared between each of the treatments. The treatments consisted of the following:

1. The sign read, "Attention: Migratory Deer Crossing." Lights were left flashing continuously. This allowed us to determine a baseline change in vehicle speed in response to a standard deer warning system.
2. The sign read, "Deer on Road When Lights are Flashing." Lights were left flashing continuously. Using these data, we evaluated whether motorists reduce their speed in response to the lights even when deer are absent.
3. The sign read, "Deer on Road When Lights are Flashing." Lights were left flashing continuously and a realistic-looking taxidermist's mount of a deer was placed in the crossing. From this we determined the effect on motorist speed of an actual deer in the crossing, after having been warned by the flashing lights.
4. The sign read, "Deer on Road When Lights are Flashing." Lights were deactivated and the deer was placed in the crossing. We used this treatment in conjunction with treatment three to evaluate whether the lights have an "alertness" effect. In other words, do motorists slow down less in response to the deer decoy when they haven't been forewarned of its presence by the lights?
5. The sign read, "Deer on Road When Lights are Flashing." Lights were activated by a remote control as motorists approached, such that motorists could see the lights come on. The deer decoy was not present during this treatment, which was used to determine whether motorists were more likely to slow down given evidence that the system was active.

Treatment 4 was not part of the original research design, but was added in early February in response to preliminary analyses that showed that motorists slowed down significantly for the deer decoy.

Results

Deer activity

Deer activity was measured using three different systems: the FLASH system, the geophone system, and the video camera system. Figure 2 (end of paper) shows the average number of hits per day during each month registered by the FLASH and geophone systems, and the average number of deer crossing per day during each month registered by the video camera. Because of frequent false hits on the FLASH system after mid-January, the average number of hits per day recorded by the FLASH system is higher than that recorded by the geophone system, showing an inflated number of hits in January, March, and April in particular (figure 2). Because of the false hits, we feel that the FLASH system is not a good method for assessing seasonal variation in deer activity.

The geophone and the video camera showed similar trends in deer activity during the time that the video camera system was operating (figure 2). Activity registered by the geophone therefore may be a good indicator of numbers of deer passing through the crossing. Because the geophone can register multiple hits for deer moving back and forth through the crossing, and because this event occurs more commonly than large groups of deer moving through the crossing simultaneously, the average number of hits per day registered by the geophone is higher than the average number of deer per day recorded by the video camera. However, because of its reliability and the fact that it closely relates to the video camera data, the geophone could be used in assessing trends in deer movement.

According to the geophone data, peak fall migration occurred primarily in November, and the peak spring migration occurred in March and April (figure 2). The fall migration occurred over a much shorter duration, while the return to the summer range in the spring was staggered over a longer period. During all months of the study period, most deer movement occurred at night, but during the fall migration a higher proportion of movement occurred during the day than during the spring migration (figure 3, end of paper).

Evaluation of FLASH and geophone system reliability

During designated periods when the FLASH and geophone system were being monitored by remote link, neither the FLASH nor the geophone system registered false hits. Additionally, all deer that passed through the crossing during the observation periods were picked up by both systems. Incidental observations of deer crossings outside the observation periods were also confirmed by hits on both systems when these were

checked after the fact. No evidence of false hits or failure to detect deer was ever found for the geophone system; it appeared to work perfectly throughout the study period, except for a period in late May when lightning caused a malfunction in the system. No evidence was found of the FLASH system failing to detect deer moving through the crossing. However, the FLASH system started registering numerous false hits starting in January due to frost, birds feeding on carrion in the crossing, and snow thrown by passing snowplows. Observations of birds in the crossing in the absence of deer were later confirmed to have registered hits on the FLASH system, but not on the geophone system. In April, a faulty transmitter caused the FLASH system to start registering false hits in response to tractor-trailers. Figure 4 (end of paper) shows percentage of false hits on the FLASH system by month from December until May.

Evaluation of FLASH system effectiveness in reducing motorist speed

Observational data from normal system operation

The effect of the normally operating FLASH system on motorist speed is shown in figure 5 (end of paper). When the FLASH sign was off and no deer were present in the crossing, motorists on average reduced their speed by 0.7 mph (95%CI +/- 0.09 n=8153) between the outside sites and the center site. When the FLASH sign was activated due to a false hit and no deer were in the crossing, motorists reduced their speed by an average of 1.4 mph (95%CI +/- 0.22 n=1965). When the FLASH sign was activated and deer were present in the crossing, motorists reduced their speed by 3.6 mph on average (95%CI +/- 0.71 n=655). Because of very large sample sizes, confidence intervals around these speed differences indicate a statistically significant difference between the three groups of cars, but we feel that a reduction in speed of 3.6 miles per hour would in reality probably not reduce the likelihood of a deer-vehicle collision.

Analyses of these data by month showed no seasonal effect, so data from December through May were pooled. Time of day and vehicle type were also analyzed separately but no effect was found; speed differences at night were comparable to day and tractor trailers and cars showed no differences in change in speed in response to the normal operation of the system.

Results of experimental manipulations

Data from experimental manipulations were analyzed for seasonal variation and variation with time of day. Neither of these factors affected vehicle speed so data were pooled with respect to month and time of day for effect of treatment and vehicle type. Results are summarized in Figure 6 (end of paper). Because sample sizes were large for all treatments, all differences in speed were significantly different from zero. However, we argue that slight reductions in speed are not likely to be biologically significant since they will probably not reduce the chance of a deer vehicle collision. Of the five treatments, only the two that involved the deer decoy resulted in reductions of speed of greater than 5 mph. Treatment 3, in which the motorist was exposed to the deer decoy and flashing lights, resulted in an average speed decrease of 11.6 (95% CI =0.67 n=1818) mph for passenger vehicles and 6.3 (95% CI=0.32 n=2703) mph for tractor-trailers. Treatment 4, in which the motorist was exposed to the deer decoy without the flashing lights, resulted in an average speed decrease of 8.24 mph (95% CI=0.79 n=1109) for passenger vehicles and 4.85 mph (95% CI= 0.40 n=1512) for tractor trailers. These results indicate that the flashing lights may have the effect of alerting some motorists to the possibility that there is a deer in the crossing and preparing them to slow down. However, the differences between treatment 3 and treatment 4 were only 3.36 mph and 2.45 mph, respectively, for passenger vehicles and tractor trailers. This seems to indicate that the lights play a trivial role in causing motorists to slow in comparison with the presence of deer in the crossing. These data, combined with the data gathered when the FLASH system was running continuously during non-treatment periods, indicate that the FLASH warning system by itself is not likely to cause motorists to reduce their speed enough to prevent deer-vehicle collisions along U.S. Highway 30 in Nugget Canyon.

Discussion

FLASH and geophone system reliability

The geophone system is more reliable than the FLASH system and should be used as a model for development of similar systems in the future. The active infrared sensors used by the FLASH system to detect deer were too prone to false hits and malfunctions to reliably operate a warning system. Over 50 percent of the hits registered by the FLASH system were not caused by deer. If motorists perceive the system to be unreliable,

they will be less likely to respond to the warning that deer are in the road. One of the advantages of the FLASH system over the geophone system is the ability to move it fairly easily to different sites as needed. Perhaps the issue of portability could be addressed by modifying the geophone to incorporate only the infrared scopes without the buried sensors that detect vibrations. Once it was properly aimed, the infrared scope on the north side of the crossing operated reliably independently of the buried sensors on the south side.

The issue of motorist perception is almost as important as the reliability of the systems themselves in determining the success of the system. If motorists that routinely pass through the crossing see deer while the lights are inactive, or the lights activated but no deer present, they are less likely to heed the warning of the flashing lights when they pass through the crossing on subsequent occasions. The FLASH system sensors were mounted close to the road, such that it was possible for a deer to trigger the sensors and be on the road after motorists had already passed the sign. Deer should optimally be detected approximately 20 seconds before they're likely to cross the road to ensure that motorists have adequate warning, which would necessitate setting the sensors fifty meters or more from the road.

FLASH system effectiveness in reducing motorist speed

Unless a deer or deer decoy was physically in the crossing, motorists did not slow down in response to the warning signs by what we feel was a sufficient amount to prevent a deer-vehicle collision. The warning lights appeared to have little effect even in terms of alerting motorists to be prepared to slow down: when the lights were turned off and a deer decoy was placed in the crossing motorists slowed down by almost the same amount that they did when the lights were operational and the deer was in the crossing. Traffic on U.S. 30 is comprised primarily of people from outside the area who may be ignorant of the risk of a deer-vehicle collision during migratory periods. Additionally, the road is heavily used by tractor-trailers that are far less likely to receive damage from a deer vehicle collision and thus are less motivated to slow down. The non-local people who pass through the crossing will encounter the sign only once and during their brief encounter probably will not fully understand how it functions. Consequently, we recommend that options involving underpasses or overpasses for movement of deer across the road be explored for this particular site. Research that will commence in September of 2001 on an underpass at the present deer crossing will hopefully prove useful in determining if underpasses are a viable alternative for this area.

Although the FLASH system is not suitable for use on US 30, it may be adaptable for use in other areas. Places that have a great deal of local traffic, where the citizens are concerned about the danger of deer-vehicle collisions, may be ideal for the application of this system. A deer-proof fence that funnels the animals into a discrete crossing, or an established, specific crossing zone associated with some natural movement corridor would be necessary in order for the system to be effective. Additionally, a program educating the local citizens about how the system works would be appropriate in conjunction with the system's installation.

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Biographical Sketch: Kelly Gordon completed her M.S. in biology at University of New Mexico in 1996. She has worked as a research scientist for the Wyoming Cooperative Fish and Wildlife Research Unit since 1999. Her ongoing research includes the assessment of an infrared sensing system that warns motorists of deer presence on roadways; a monitoring project of underpasses along Interstate 80 in Wyoming; research into deer response to varying aperture sizes on an underpass in western Wyoming; and a research program examining the impacts of recreational shooting on prairie dogs in Thunder Basin National Grassland, Wyoming.

References

- Clevenger, Anthony P.; Chruszcz, Bryan, and Gunson, Kari E. Highway mitigation fencing reduces wildlife-vehicle collisions. *Wildlife Society Bulletin*. 2001; 29(2):646-653.
- Edberg, S.C. 1990. Wyoming Range mule deer mortality study, fourth year summary 1989- 1990. Unpubl. Report, Wyoming Game and Fish Department, Jackson, WY.
- Feldhamer, George A.; Gates, J. Edward; Harman, Dan M.; Loranger, Andre J., and Dixon, Kenneth R. Effects of interstate highway fencing on white-tailed deer activity. *Journal of Wildlife Management*. 1986; 50(3):497-503.

- Forman, Richard T. T. and Alexander, Lauren E. Roads and Their Major Ecological Effects. *Annual Review of Ecology and Systematics*. 1998; 29:207-231.
- Foster, Melissa L. and Humphrey, Stephen R. Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin*. 1995; 23(1):95-100.
- Hunt, Alison; Dickens, Helen J., and Whelan, Robert J. Movement of Mammals through Tunnels under Railway Lines. *Australian Zoologist*. 1987; 24(2):89-93.
- Lehnert, Mark E. and Bissonette, John A. Effectiveness of highway crosswalk structures at reducing deer-vehicle collisions. *Wildlife Society Bulletin*. 1997; 25(4):809-818.
- Ludwig, John and Bremicker, Timothy. Evaluation of 2.4m Fences and One-Way Gates for Reducing Deer-Vehicle Collisions in Minnesota. *Transportation Research Record*. 1983; 913:19-22.
- Pojar, Thomas M.; Prosenice, Richard A.; Reed, Dale F., and Woodard, Thomas N. Effectiveness of a lighted, animated deer crossing sign. *Journal of Wildlife Management*. 1975; 39(1):87-91.
- Reed, Dale F. Mule deer behavior at a highway underpass exit. *Journal of Wildlife Management*. 1981; 45(2):542-543.
- Reeve, Archie F. and Anderson, Stanley H. Ineffectiveness of Swareflex Reflectors at Reducing Deer-Vehicle Collisions. *Wildlife Society Bulletin*. 1993; 21(2):127-132.
- Romin, Laura A. and Bissonette, John A. Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. *Wildlife Society Bulletin*. 1996; 24(2):276-283.
- Romin, Laura A. and Dalton, Larry B. Lack of response by mule deer to wildlife warning whistles. *Wildlife Society Bulletin*. 1992; 20:382-384.
- Schafer, James A. and Penland, Stephen T. Effectiveness of swareflex reflectors in reducing deer vehicle accidents. *Journal of Wildlife Management*. 1985; 49(3):774-776.
- Singer, Francis J. and Doherty, Jonathon L. Managing Mountain Goats at a Highway Crossing. *Wildlife Society Bulletin*. 1985; 13:469-477.
- Ujvari, Marianne; Baagoe, Hans J., and Madsen, Aksel B. Effectiveness of wildlife warning reflectors in reducing deer vehicle collisions: a behavioral study. *Journal of Wildlife Management*. 1998; 62(3):1094-1099.
- Ward, A. Lorin. Mule Deer Behavior in Relation to Fencing and Underpasses on Interstate 80 in Wyoming. *Transportation Research Record*. 1982; 859:8-13.
- Waring, G. H.; Griffis, J. L., and Vaughn, M. E. White tailed deer roadside behavior, wildlife warning reflectors, and highway mortality. *Applied Animal Behaviour Science*. 1991; 29:215-223.
- Yanes, Miguel; Velasco, Jose M., and Suarez, Francisco. Permeability of roads and railways to vertebrates: the importance of culverts. *Biological Conservation*. 1995; 71:217-222.

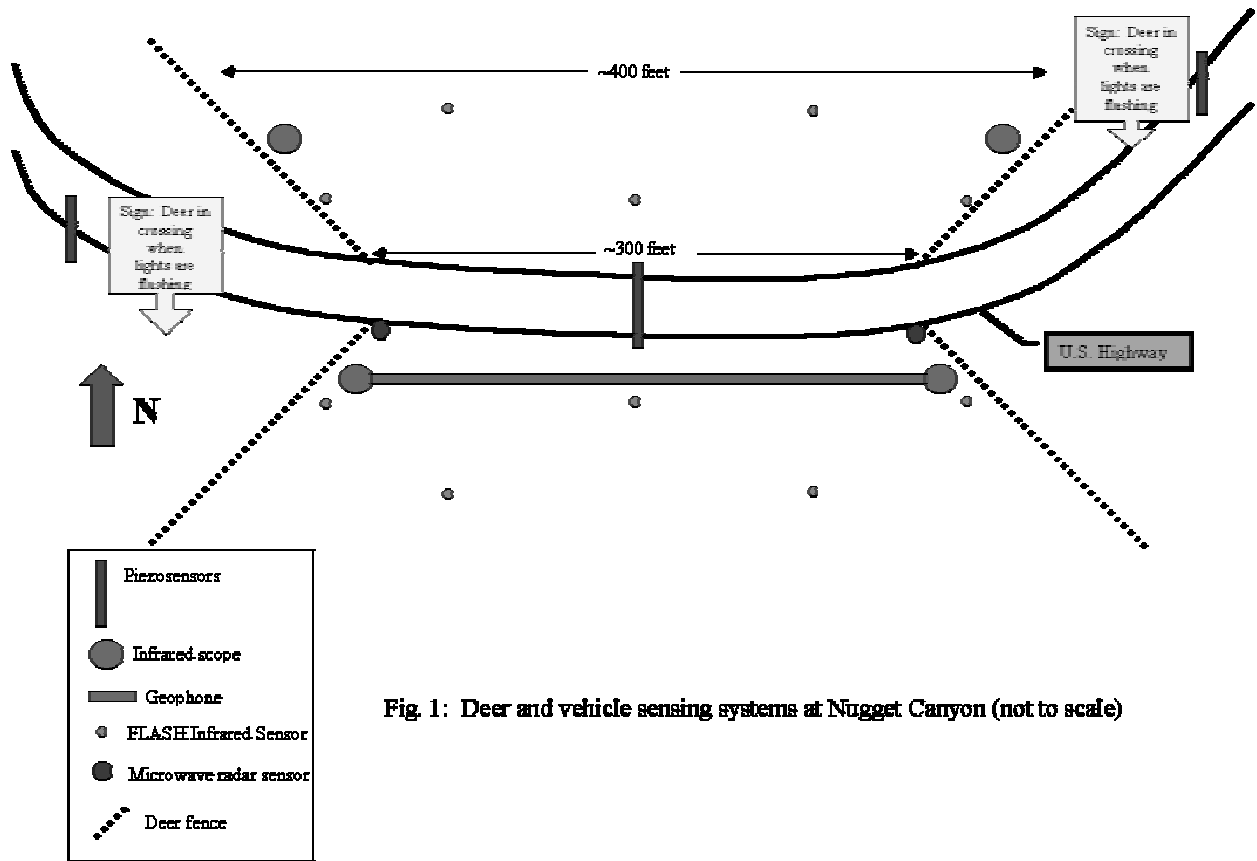


Fig. 1: Deer and vehicle sensing systems at Nugget Canyon (not to scale)

Figure 2: Average daily deer activity by month for three deer detection systems

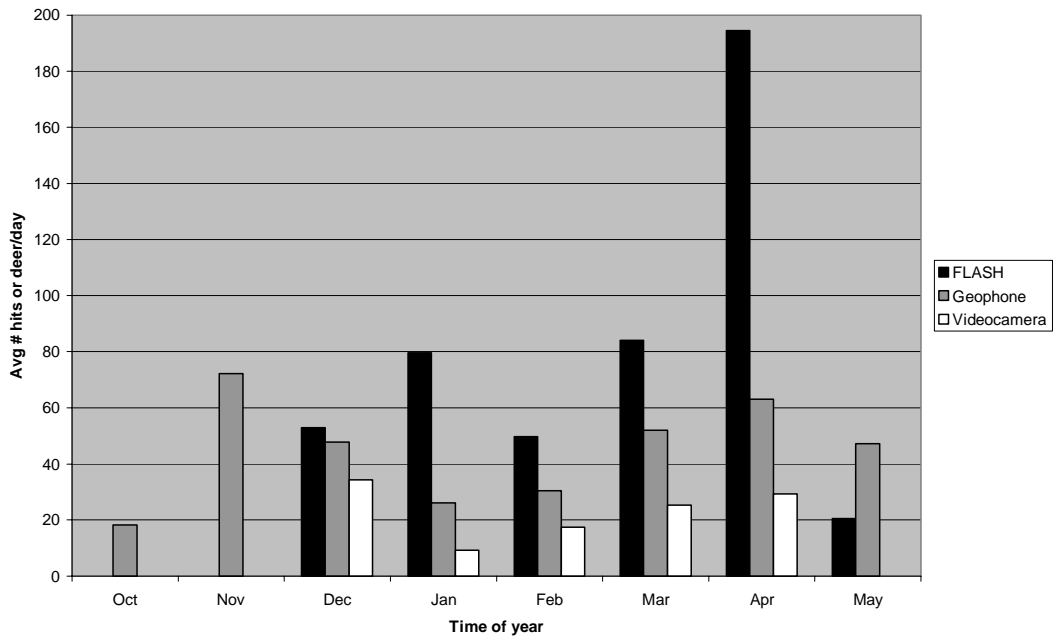


Fig. 3: Night/Day Deer Activity at Nugget Canyon

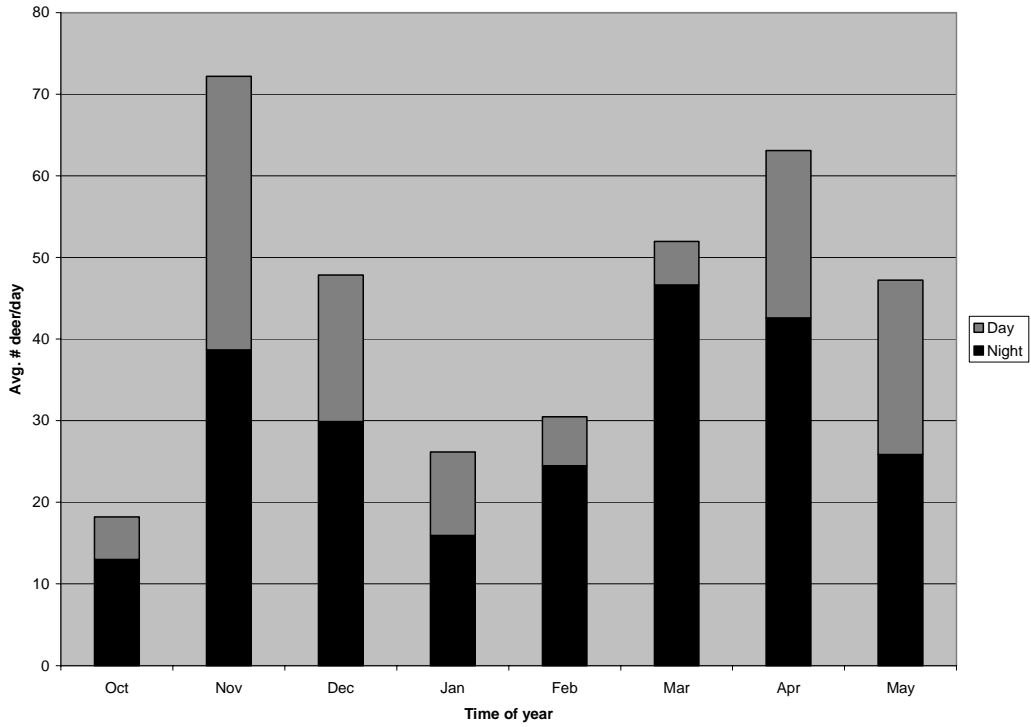
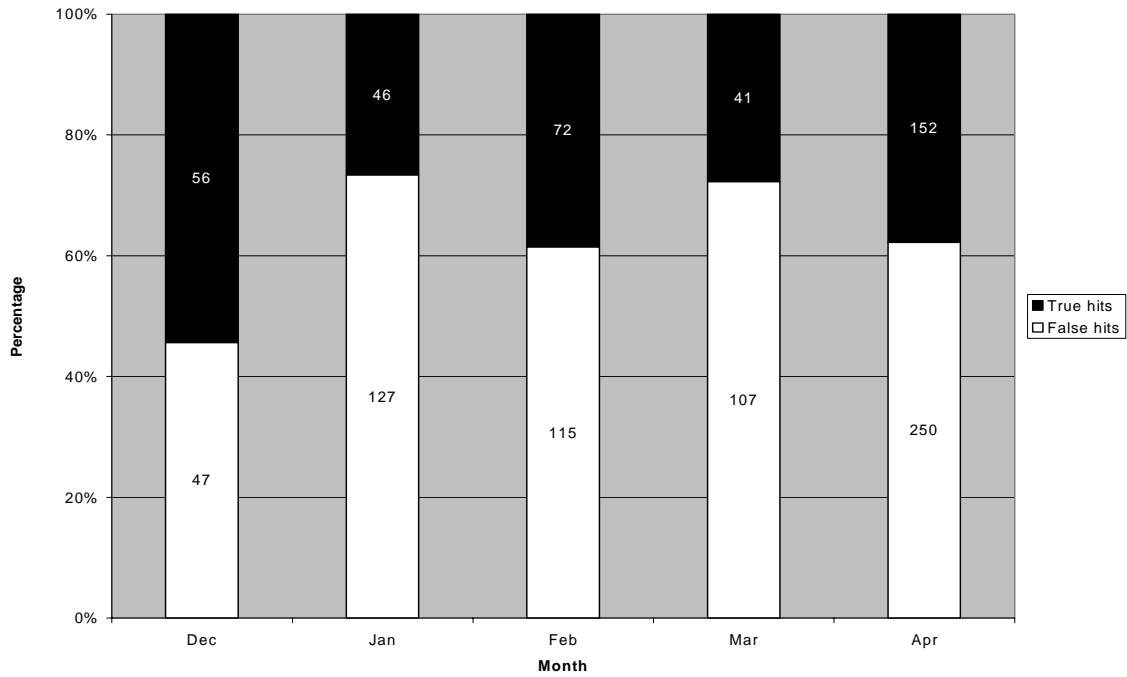


Fig. 4: Percentage of false hits on the FLASH system by month



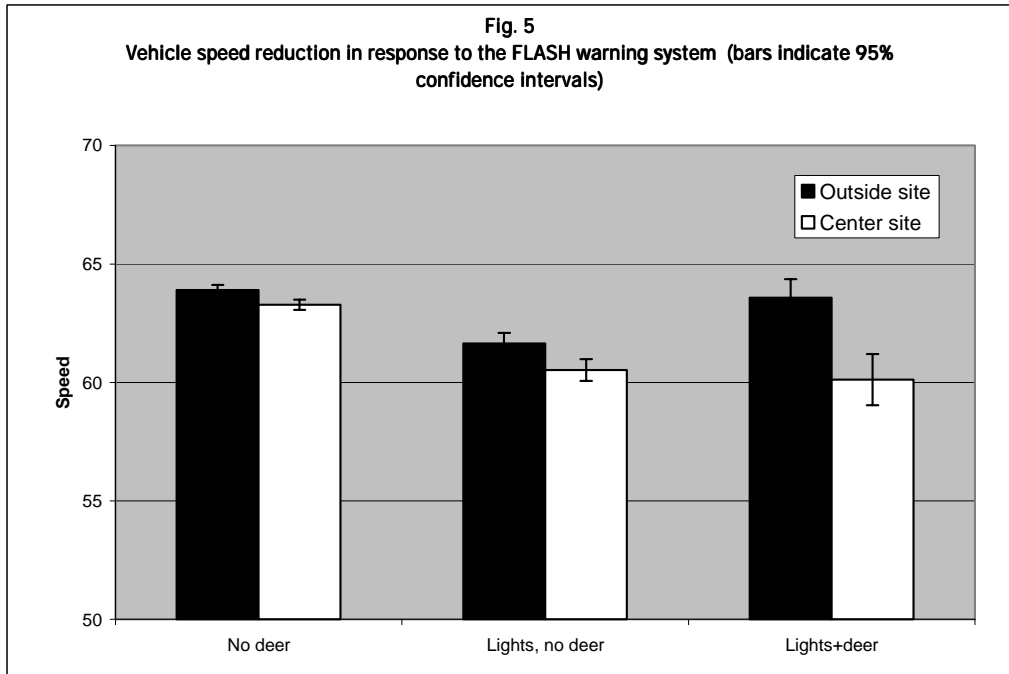


Fig. 6: Motorist speed before and after encountering warning system in response to five different experimental treatments (see text for description of treatments; bars indicate 95% confidence intervals)

