February 1991

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Don M. Jordan Jr.  
U. S. Fish and Wildlife Service, New York Cooperative Fish and Wildlife Research Unit, Cornell University, Ithaca, NY

Milo E. Richmond  
U. S. Fish and Wildlife Service, New York Cooperative Fish and Wildlife Research Unit, Cornell University, Ithaca, NY

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DON M. JORDAN, JR., U. S. Fish and Wildlife Service, New York Cooperative Fish and Wildlife Research Unit, Cornell University, Ithaca, NY 14853-3001
MILO E. RICHMOND, U. S. Fish and Wildlife Service, New York Cooperative Fish and Wildlife Research Unit, Cornell University, Ithaca, NY 14853-3001

Abstract: We conducted experiments with behavioral conditioning of white-tailed deer (Odocoileus virginianus) using vertical 3-wire, electrified fencing modified with either an attractant or a repellent in order to test the idea that an attractant or repellent coupled with an electric shock, would be a more effective deterrent than a random shock or no shock at all. Enclosures measuring 6 x 6 m with 3 wires at heights of 50, 100, and 150 cm were established at 2 study sites in Tompkins County, New York. Each site contained 4 exclosures which were either nonelectrified (control), electrified, electrified with an attractant, or electrified with a repellent. We baited each exclosure with fresh apples to ensure deer visitation by deer. All exclosures were monitored daily to determine her visitation, disappearance of apples, and to measure fence voltage. Data from 116 days indicate that the electric fence with a repellent excluded deer most effectively. Deer penetrated this type of exclosure only once. Electricity and attractant ranked second, and electricity alone ranked third in effectiveness for excluding deer. The control was the least effective barrier (37 encroachments).

Increasing human populations, urbanization of rural areas, and increasing populations of white-tailed deer cause more frequent interactions between humans and deer. This increase in interactions corresponds with an increase in deer damage incurred by fruit growers, nurseriesmen, and other groups (McAninch and Fargione 1987). Damage and economic losses sustained by farmers (Hygnstrom and Craven 1988), orchardists (Phillips et al. 1987, Purdy et al. 1987), nursery growers (Sayre and Decker 1990), and even gardeners and ornamental plant owners (Sayre and Decker 1990) have brought about the need for improved deer control techniques.

Little work has been done combining electric fencing with repellents or attractants. Separately, fencing and repellents have been found to reduce damage, and perhaps together they have a synergistic effect. We hypothesize that the addition of a repellent to an electric fence would double the negative reinforcement for deer. The repellent itself may cause the deer to avoid the fence. However, if a deer does attempt to enter the fence and receives a shock, the combination of the repellent and the shock may cause the deer to recognize and avoid the fence in the future. Coupling the electric shock with an attractant, to ensure that the encroaching deer receives the shock, may also enhance fence effectiveness. Peanut butter was used as an attractant to encourage deer to touch the electric wires with sensitive parts of their bodies (i.e., their tongue or nose). This, we hypothesize, results in a sufficiently severe shock for deer, and would cause conditioned animals to avoid fenced areas in the future. The use of peanut butter has been found effective with single-wire fences exposed to light deer pressure (Kinsey 1976, Porter 1983, Hygnstrom and Craven 1988), and may therefore enhance the effectiveness of the 3-wire design. We report here on the testing of the 3-wire electric fence with attractants and with repellents to determine its effectiveness as a deer exclosure.

STUDY AREA

Two sites in the Town of Dryden, Tompkins County, New York were selected for this fencing study. Site 1 was in Varna, a rural area 4 km east of the City of Ithaca, southeast of Cayuga Lake. The exclosures were in a 16-ha field owned by Cornell University. The field was used primarily for experimental vegetable crops, and was bordered on one side by County Route 366, and by a mixed hardwood-conifer woodlot and Fall Creek on the other sides. Hunting was not allowed in the bordering woodlots.

Site 2 was in Ellis Hollow, another rural area about 5 km southeast of Ithaca and 3 km southeast of the Varna site. Exclosures were in a privately-owned 3-ha field of goldenrod (Solidago spp.) and red-osier dogwood (Cornus stolonifera). The field contained a pond, bordered by county roads to the north and west, and a mixed hardwood-conifer woodlot to the south and east. The area immediately surrounding the field provided excellent deer cover. Private ownership greatly limited hunting.

The density of deer in the study area is not known. The New York State Department of Environmental Conservation (DEC) uses buck-take/km² as their primary index for population estimates. For the 250-km² Town of Dryden, which encompasses both study sites, the average buck-take from 1985-1989 was 1.2 bucks/km².

Although information about buck harvest at the Varna site was not available it would seem that deer numbers in this area were at least as high as the town average. In reality, deer numbers were likely higher because of the ideal mix of cover and the lack of hunting pressure. Landowner data on deer take from the Ellis Hollow site suggest that deer densities in this area (3.6 bucks/100 acres, n = 22 years) were higher than the rest of the

A series of pellet-count transects were conducted at Ellis Hollow during April 1990, and an average of 89.3 pellet groups/ha (SE = 22.3, n = 14 transects) were found. Deer sign (including tracks, runs, and fecal pellets) and deer sightings (during the day and at night using spotlights) indicated that deer frequented both study sites. Although actual deer numbers were not known, a combination of the population indices and personal sightings indicate that there were medium-to-high deer numbers near the exclosures.

METHODS

Fencing efforts began in the summer of 1990. Four 6 x 6 m exclosures were established at each of the 2 study sites. Excluses were randomly selected to receive 1 of 4 treatments: (1) no electricity (control), (2) electricity, (3) electricity and an attractant, or (4) electricity and a repellent. The excluses were vegetated inside and 1 m around each plot was cut with a lawn and plastic corner insulators, 3 wires were connected to the posts at lower heights. Lower wires were added to the fences at heights of 10 and 25 cm to provide little physical barrier to the deer, but necessary to keep the soil friable.

A 1 x 1 m area was dug in the center of each plot, and to soil was trimmed periodically using a lawn mower and weed whip. Fresh peanut butter and Jersey were placed on the cloth every 3-4 weeks to ensure that they continued to act as attractants or repellents.

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RESULTS

The electric fence with the repellent Jersey most effectively excluded deer, as this design was only penetrated once (0.9% of total exposure days, Table 1). The electric fence with the peanut butter attractant was second most effective, experiencing only 9 (7.8% of total exposure days) encroachments. The electric fence alone ranked third most effective, as deer penetrated this design 13 times (11 % of total exposure days). As expected, the least effective fence was the nonelectrified control. Deer penetrated the 2 control plots approximately 32% of the days. More than 300 apples were removed by deer during the 37 known instances of deer encroachment.

Table 1. Deer encroachment by fence design at study sites near Ithaca, New York, 1990-91.

<table>
<thead>
<tr>
<th>Fence Design</th>
<th>Days of Plots</th>
<th>Instances of Deer Damage</th>
<th>Apples taken by Deer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2</td>
<td>116</td>
<td>37</td>
</tr>
<tr>
<td>Electric</td>
<td>2</td>
<td>116</td>
<td>13</td>
</tr>
<tr>
<td>Attractant &amp; Electric</td>
<td>2</td>
<td>116</td>
<td>9</td>
</tr>
<tr>
<td>Repellent &amp; Electric</td>
<td>2</td>
<td>116</td>
<td>1</td>
</tr>
</tbody>
</table>

Deer entered the control exclosures more frequently than expected (X^2 = 32.27, 3 df, P < 0.01), and deer penetrated the electric fences with Jersey less frequently than expected (X^2 = 13.07, 3 df, P < 0.01). Deer penetrated the electric fence alone or the fence with peanut butter as often as expected.

The addition of 2 lower electrified wires kept out some small mammals, but were not an absolute barrier. The nonelectrified fence had little effect, as 560 apples (20.1% of all apples placed in both exclosures) were removed or damaged by small mammals. The 3 electrified fence designs reduced encroachment by small mammals. Only 385 (13.8%) apples were damaged or removed from exclosures treated with electric and peanut butter; 330 (11.9%) from exclosures with electric fences without attractant or repellent, and 210 (7.5%) from exclosures with electricity and Jersey.

DISCUSSION

Fencing has been one of the most effective controls for deer damage. Previously, most fencing efforts focused on conventional nonelectrified, woven-wire designs (Ellingwood et al. 1985). The most effective fence has been the 2.4-m vertical, woven-wire design (Caslick and Decker 1979, McAninch and Winchcombe 1981, Craven 1983). Although this design pro
vides a formidable barrier to deer, the predominant objection to
conventional fencing techniques has been high construction costs
(Table 2). According to Ellingwood and McAninch (1984),
construction of an 2.4-m woven-wire fence costs $15.88 per linear
meter (adjusted to 1991 prices). Consequently, conventional fences in
areas of intensive agriculture, such as orchards or private gardens, have
been limited (Harder 1968, Craven 1983). Furthermore, its large size
and great visual impact makes an 2.4 m fence impractical for
homeowners and gardeners.

Table 2. Prices and cost-effectiveness of basic deer fencing designs
compared to the vertical 3-wire electric fence.1

<table>
<thead>
<tr>
<th>Design</th>
<th>Cost/linear m</th>
<th>Level of deer pressure at which fence is cost-effective</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4-m woven-wire</td>
<td>$15.88</td>
<td>High</td>
</tr>
<tr>
<td>nonelectric 7-strand</td>
<td>6.30</td>
<td>Moderate-high</td>
</tr>
<tr>
<td>slanted electric fence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical 5-wire electric fence</td>
<td>3.25</td>
<td>Moderate-high</td>
</tr>
<tr>
<td>Vertical 3-wire electric fence</td>
<td>2.59</td>
<td>?</td>
</tr>
</tbody>
</table>

1 Costs from Ellingwood and McAninch (1984), adjusted to 1991
prices.

Recent developments in fencing technology, including
high-tensile wire and powerful, dependable fence chargers, have
increased the popularity of electric fences. This, coupled with improved
designs, has increased the efficacy of electrical fencing and provided the
public with a variety of control options. Of such design, the 7-strand
slanted fence (Ellingwood et al. 1985), successfully excludes deer at
high deer pressure (McAninch 1980, McAninch and Winchcombe
1981). With a construction cost of $6.30 per linear meter (Table 2), this
fence is much less expensive than the 2.4-m woven-wire fence.
However, its spacious and complex design are impractical for homes
and gardens. The vertical 5-wire fence (Ellingwood et al. 1985), also
known as the Penn State electric fence, has been an effective deer
exclosure (Palmer et al. 1983, Palmer et al. 1985, Kochel and
Brenneman 1987). Low cost of $3.25 per linear meter (Table 1) and
easy construction have increased the popularity of the 5-wire fence with
homeowners. In spite of recent improvements in design and materials,
fencing costs must be further reduced for practical use by the nursery
owner, home gardener, and commercial vegetable grower.

The vertical, 3-wire electric fence at $2.59 per linear meter (Table
2) is less expensive than the 5-wire fence. Its simple structure is
practical for use by ornamental plant owners and gardeners. At
medium-to-high deer pressures, the 3-wire design with attractants or
repellents appeared to provide an effective deer exclosure.

The nonelectric fence was the least effective deer exclosure. Deer
either crawled under, went through, or jumped over it little
difficulty. The addition of electricity clearly increased effectiveness
of the design. A possible drawback of electric alone is that many
times deer going through the fence contact the wire with
insensitive parts of their body (i.e., n back, or chest), resulting in a
shock too mild to deter the an (McKillop and Sibly 1988). In
addition, deer that recently electrical shocks to random parts of
their body may not ate the pain with the fence, and as a result, may
experience li aversive conditioning.

The combination of electricity and repellent may be effective because
the presence of the electricity provides a second level deterrent.
Without electricity, a deer that ignores the repellent would have little
trouble crossing the fence. However, a deer that initially ignores the
repellent and then receives a shock while trying to enter the fence may
avoid the fence in the future because of the dual aversive
conditioning.

Deer appeared to exhibit a conditioned avoidance of the fences
equipped with the peanut butter and Jersey. McKillop and Sibly (1988)
state that most animals can learn an immediate and long-lasting
avoidance of objects associated with unpleasant experiences. It would
be useful to continue studies of learned behavior in both captive and
free-ranging deer, and attempt to take advantage of this conditioned
avoidance phenomenon. Studies of multiple-cueing, or simply th
identification of key signals that warn deer (i.e., flagging,
unusually-shaped objects, odor-based repellents, etc.) may prove quite
fruitful in a search for new deer management strategies.

MANAGEMENT IMPLICATIONS

The vertical, 3-wire electrified fence modified with the addition of
a deer repellent provided an effective barrier to deer encroachment at
medium-to-high deer densities. With its small
visual impact, simple design, and relatively-low construction costs, the 3-wire fence could be further developed as an inexpensive and viable control of damage in many situations, especially those faced by homeowners and gardeners. Although the use of electrified fencing may be inappropriate in areas frequented by humans, particularly children, further investigation into the duration of conditioned-fence-avoidance behavior by deer may reduce the amount of time necessary to keep the fence electrified.

LITERATURE CITED