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Abstract: Deer frequently visit areas where they may cause damage. Incidents along roadways and runways inflict numerous injuries to animals and humans, and cause considerable economic losses. Concerns are increasing that deer interactions with domestic animals may contribute to spread of disease. Deer foraging in residential areas, agricultural fields, or plant propagation sites can impede growth and possibly survival of desirable plants. We conducted a series of trials to determine whether mild electric shock would induce place avoidance in deer. Shock was delivered through a device attached to a collar. A noise cue was emitted as an animal approached a defined area if the animal failed to retreat a shock followed. Deer learned to avoid areas associated with shock. We concluded that place avoidance induced through negative reinforcement may be a feasible means to protect valuable resources from resident animals. However, the technological limitations of tested devices, costs to implement, and required training for individual deer reduced the practicality of this approach for highly mobile animals and as a means to protect resources with low economic significance.

Key words: Behavior, deer, electrical shock, site avoidance, training, wildlife damage management

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INTRODUCTION

Deer (*Odocoileus* spp.) occur across the United States and provide many desirable recreational and aesthetic opportunities (Nolte 1999). However, problems associated with deer are increasing. Human encroachments on historic ungulate ranges and increasing deer populations have increased interactions with deer; thus problems (Alverson et al. 1988, Stromayer and Warren 1997). Other problems reflect changing behaviors demonstrated by urban or suburban animals (McCullough et al. 1997). For example, using sidewalks as movement corridors and gardens as food sources. Foraging deer negatively impact grain crops, forage crops, vegetables, fruit trees and ornamentals (Craven and Hygnstrom 1994). As ungulate populations expand they pose a widespread detriment to reforestation efforts (Rochelle 1992). Ungulates commonly occur on or near roadways and along airport runways, creating hazards to themselves and to humans (Conover 1997). There also is an increasing awareness of the potential for deer to serve as vectors for reservoirs for human or animal diseases (Kaneene et al. 2002).

Hunting is the traditional means to suppress deer populations (VerCauteren and Hygnstrom 1998), but it is often impractical for solving site-specific problems. Fencing is the most effective method to impede ungulate movements (Nolte 1998, 1999). Fencing, however, can be cost prohibitive to install ($13 to $100 thousand/km) and to maintain ($100 to $1000/km/year; Reed et al. 1982, Romin and Bissonette 1996). Traditional frightening devices, such as propane cannons and scarecrows are generally ineffective even over short intervals (Koelhler et al. 1990, Belant et al. 1996). Devices activated by an animal=s presence are generally more effective than permanent or routine displays (Nolte 1999). Further, a device affixed to individual deer may permit greater control of those individuals, and possibly any accompanying conspecific.

Animals learn not to exhibit behaviors if the behaviors are associated with a negative reinforcer, such as an electrical shock. The psychological literature is replete with demonstrations that response-contingent shock suppresses responding and that the magnitude of suppression is directly related to intensity of the shock (see MacKintosh 1974). Thus, it should be possible to train animals to avoid areas or objects by repeatedly pairing their approach to the target stimulus with an electrical shock. Electric dog-training collars activated when coyotes approached sheep reduced predation (Linhart et al. 1976, Andelt et al. 1999). Electric collars and ear tags have shown promise for deterring cattle from protected areas, such as riparian zones (Quigley et al. 1990, Tiedeman et al. 1998). We conducted a series of trials to provide insight as to whether electrical shock was a feasible approach to induce place avoidance in deer. Further, we tested whether avoidance could be transferred to another site if cues (e.g., traffic cones) surrounding the training site were moved to a new location. Finally, we investigated whether the avoidance extinguished when the negative reinforcer was deactivated.

METHODS

Subjects

Six adult black-tailed deer (*Odocoileus hemionus*) were selected from a resident herd maintained at the National Wildlife Research Center Olympia Field Station, Olympia, Washington. These animals were randomly divided in two groups of 3 deer and placed in separate of approximately 1.5 ha that were pastures designated as pastures A and B. Pastures contained native grasses and deer were provided free access to their normal pellet diet and fresh water throughout the study. Shelters (4m x 4m) provided deer an escape from weather conditions. Numbered ear-tags were used to identify individual deer.

Delivery of Negative Reinforcer

An INNOTEK™ Containment System (INNOTEK™ 1000 Fuller Drive, Garrett, IN 46738) was adapted to our experimental paradigm to assess deer responses. The INNOTEK™ system, frequently referred to as an invisible fence, is normally installed to enclose dogs within a perimeter. A sound followed by an electric shock is emitted when a collar approaches the perimeter. Our objective was for animals entering protected plots to receive the same cue and negative reinforcer, but for the shock to continue as long as they remained within the protected plot. Therefore, our wire installation varied from the guidelines offered by INNOTEK™. Nor did we follow procedures recommended by INNOTEK™ to train dogs to stay within a given perimeter. Thus, our experimental approach did not evaluate efficacy of the INNOTEK™ Containment System *per se*, and results should not be interpreted to reflect on the product.

Collars receive signals through a wire buried a few centimeters beneath the ground and powered by a standard 110-volt transmitter. When activated the collar receiver emitted a warning tone for approximately 2 seconds, followed by a shock if the animal did not retreat. The intensity of the initial mild shock increased if the animal remained in the protected plot. The shock ceased when the animal exited the field or after 20 seconds. If the animal remained in the field another 20-second shock was emitted after a 10 second delay and the process repeated until the animal vacated the plot. The collar receiver operated on a 6-volt alkaline battery.

Experimental Approach

Four, 20 x 20 m plots were established in each pasture, corners were delineated with wooden stakes. We randomly selected 2 plots to install the test devices. Wire was buried at a 2-cm depth, along the plot perimeter and in parallel lines, 4-m apart, throughout the plot interior. INNOTEK™ instructions cautioned that wire placed within 3-m of other wires may cause malfunctions. We assessed whether plots were protected adequately by walking towards plots carrying a collar receiver and listening for the warning tone. Repeated attempts indicated it was not possible for animals to approach or to be inside a fenced, activated plot without activating their collars. However, animals could enter deactivated plots without hearing the warning tone or being shocked if their transmitter was turned off.

Deer activity was indirectly measured by counting number of bites taken from seedlings planted within plots. Prior studies indicated that western red-cedar (*Thuja plicata*) were attractive to deer and that bite counts were reliable indicators of deer activity (Nolte et al. 2001). Sixteen western red-cedar seedlings spaced at 1 m intervals were planted in 4 equal rows centered in each plot. One meter separated the middle two rows, while the outside rows were 2 m apart. Stakes (6, 50-cm stakes/row at 1-m intervals) were inserted in rows located between the first and second rows of seedlings and between the third and fourth rows. Headless nails protruding from the top of stakes were used to hold apple slices (approximately 1/16 of a golden delicious apple). Birds frequently consumed apple slices, so apple counts were not reliable indicators of activity. However, because apples were a desirable food, slices were replaced daily to entice deer to enter plots. New tree seedlings were planted in plots before each trial. Seedlings were examined daily (approximately 0900) for damage and number of bites recorded. Bite counts were limited to a maximum of 25, because after 25 bites seedlings were virtually defoliated. Seedlings pulled out of the ground were regarded as completely defoliated and thereafter recorded as having had 25 bites.

A series of plot treatment configurations across 7 periods was used to assess whether deer differentiated among activated and non activated plots (Figure 1). Each period consisted of 3 or 4 consecutive days. We planted new seedlings at the beginning of each period, and recorded bite counts daily. Electrical systems were not installed on plot 2 or plot 4, thus they always served as unprotected controls. A hand-held collar was used to ensure active plots were emitting signals prior to each trial. We monitored initial response of deer during Period 1 by activating a single plot.

Figure 1. Experimental treatments applied to plots for each trial period. Cones indicate that fluorescent orange traffic cones surrounded a plot. Active means the electrical shock delivery system was active during the period. Systems were not installed on plot 2 or plot 4. Line of cones indicates cones where placed in a line across a pasture rather than around a plot.

Plot Number	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7
Plot # 1	Cones Active	Cones Active	No Cones Inactive	No Cones Inactive	Line of Cones	Cones Active	Cones Inactive
Plot # 2	No Cones	No Cones	No Cones	No Cones	Line of Cones	No Cones	No Cones
Plot # 3	No Cones Inactive	Cones Active	Cones Active	Cones Inactive	Line of Cones	Cones Active	Cones Inactive
Plot # 4	No Cones	No Cones	No Cones	No Cones	Line of Cones	No Cones	No Cones

Fluorescent orange traffic cones (45 cm) were placed around the perimeter of plot 1 immediately before it was activated. One cone was placed at each corner and two cones were interspersed evenly along sides.

We encircled plots #1 and 3 with cones and activated them during Period 2 to determine if deer activity in an inactive plot ceased when it was activated, or if their prior unencumbered experience within a plot hindered efforts to deter them.

Next, we evaluated whether limited exposures during periods 1 and 2 had trained deer to avoid a specific area or possibly an area defined by cones. Therefore, during Period 3, we deactivated plot 1 and removed the cones, leaving plot 3 active with cones. Subsequently, during Period 4, we deactivated plot 3 but left the cones in place.

Avoidance of cones was further tested during Period 5. Deer were herded to a corner, then cones were placed in a line across a pasture at 5-m intervals. Two persons then approached deer from the opposite side motivating the animals to cross the pasture. Motivators walked slowly and quietly behind deer at a minimum distance of 10 m. Deer merely walked in front of the motivators, and as they approached the line of cones the motivators stopped and observed their response.

Periods 6 and 7 were an extended repetition of prior trials to further assess rate deer avoidance of treated plots extinguished once the systems were deactivated. During Period 6, electric systems protecting plot 1 and plot 2 were active, with cones surrounding the perimeter. The systems were not active during Period 7, but cones remained in place. We conducted these trials in Periods 6 and 7 only with deer in Pasture A.

Statistical Analysis

Deer activity was not consistent between pastures, therefore the trials were regarded as case studies. A single factor

Analysis of Variance was used to assess differences among plots in the number of bite counts on day 3 for each period. Plot treatment varied among periods; therefore we did not analyze the data to detect differences across periods. Tukey tests were used to differentiate among plot means, $P \leq 0.05$ was considered significant. Although we pseudo-replicated, because samples rather than replicates were used in the analysis, the results do provide some insight for deer activity differences.

RESULTS

Period 1: Deer did not browse seedlings in the treated plot in either pasture. Seedling damage among the untreated plots in pasture A varied; one plot was untouched while seedlings in another plot were completely defoliated (Figure 2a). Damage among untreated plots in pasture B was similar and all untreated plots had significantly more damage than the treated plot (Figure 2b).

Period 2: Number of bites inflicted to seedlings in treated plots was significantly less than in untreated plots in pasture A (Figure 3a). Again, deer were not consistent in their response to seedlings in untreated plots. Deer did not inflict any browse damage to seedlings on treated plots in pasture B. Bite counts were similar on untreated plots, and these were significantly greater than counts recorded for treated plots (Figure 3b).

Period 3: Bites taken from seedlings on plots 1 and 3 were similar in pasture A. Fewer bites were taken on plots 1 and 3 than on plot 4, which had a lower bite count than recorded for plot 2 (Figure 4a). In pasture B, significantly fewer bites were taken from seedlings in plot 3 than from seedlings in other plots (Figure 4b). Bite numbers recorded for plot 1 and plot 2 were similar, but bites on plot 4 were less frequently detected on other untreated plots.

Period 4: Bite counts varied among plots in pasture A (Figure 5a). Deer inflicted the fewest bites to seedlings in plot 4, and the most in plot 2. The bite count for plot 3 was not significantly different than plot 4, but seedlings on these plots suffered significantly fewer bites than seedlings on plots 2. Bite counts were similar for all plots in pasture B (Figure 5b).

Period 5: Deer behavior observed during period 5 was similar for herds in pastures A and B. The lead deer approached the cone line slowly, appeared to hesitate a couple meters in front of the line, then bolted across the line. The deer ran approximately 10 meters past the line then stopped and looked back in the direction of the motivators. The other two deer lagged a short distance behind the lead deer, then they too ran across the line following the lead deer when it bolted.

Period 6: No bites were inflicted on seedlings in plots 1 and 3 in pasture A. Bite count on these plots was significantly less than in untreated plots (Figure 6a). Seedlings in plot 4 had fewer bites than plot 2.

Period 7: Deer response to seedlings was not consistent among plots (Figure 6b). However, differences were not between previously treated and untreated plots. The least amount of activity was detected on plot 4, a plot that was never protected. Seedling damage recorded for plot 1 was than that recorded for plot 2. However, bite count for plot 3 was not significantly different than counts for plots 1 or 2.

Figure 2. Mean daily bites taken by deer from plots on pasture A (a) and pasture B (b) during period 1. Cones and Hot indicates traffic cones were placed around the plot perimeter and the electrical stimulation device was active. Control indicates the plot did not have cones and the electrical stimulation device was either inactive or absent.

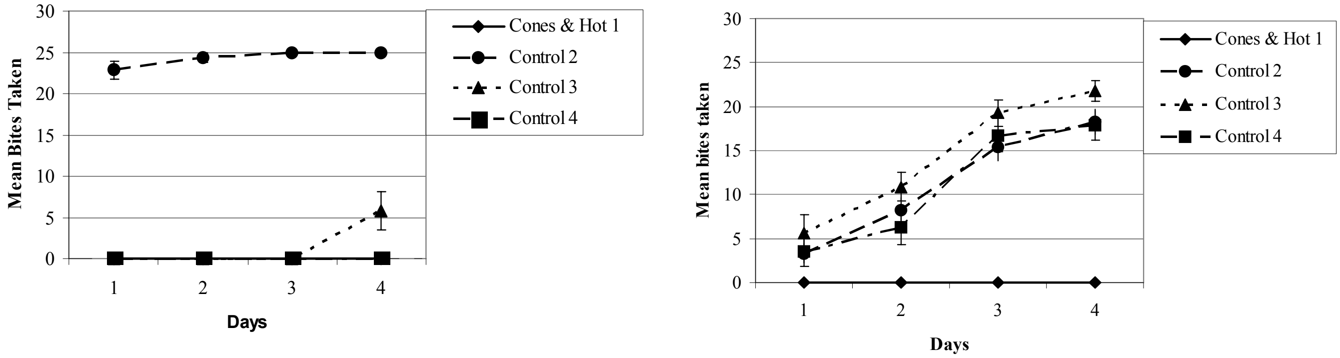


Figure 3. Mean daily bites taken by deer from plots on pasture A (a) and pasture B (b) during period 2. Cones and Hot indicates traffic cones were placed around the plot perimeter and the electrical stimulation device was active. Control indicates the plot did not have cones and the electrical stimulation device was either inactive or absent.

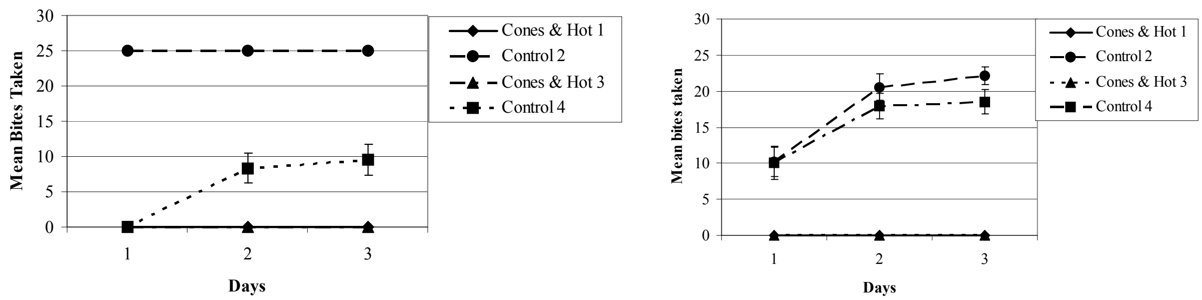


Figure 4. Mean daily bites taken by deer from plots on pasture A (a) and pasture B (b) during period 3. Cones and Hot indicates traffic cones were placed around the plot perimeter and the electrical stimulation device was active. Control indicates the plot did not have cones and the electrical stimulation device was either inactive or absent.

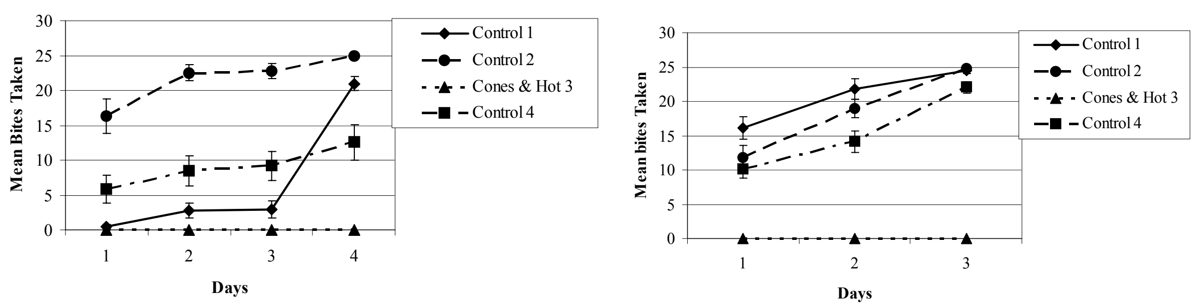


Figure 5. **Mean daily bites taken by deer from plots on pasture A (a) and pasture B (b) during period 4. Cones and Hot indicates traffic cones were placed around the plot perimeter and the electrical stimulation device was active. Control indicates the plot did not have cones and the electrical stimulation device was either inactive or absent.**

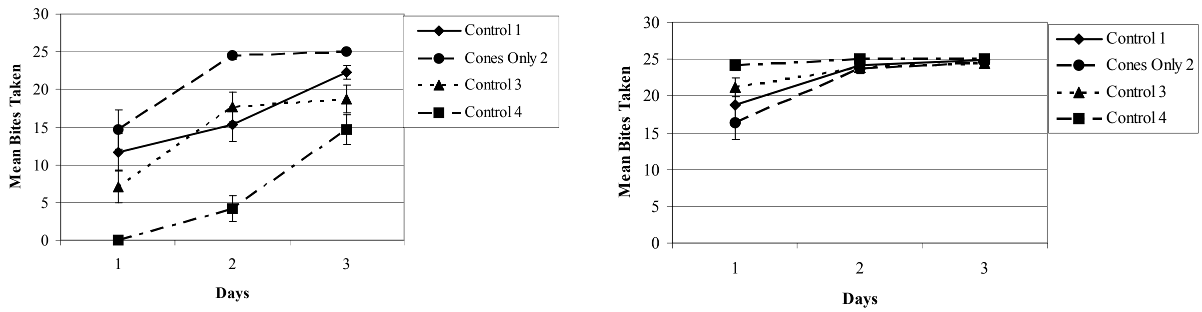
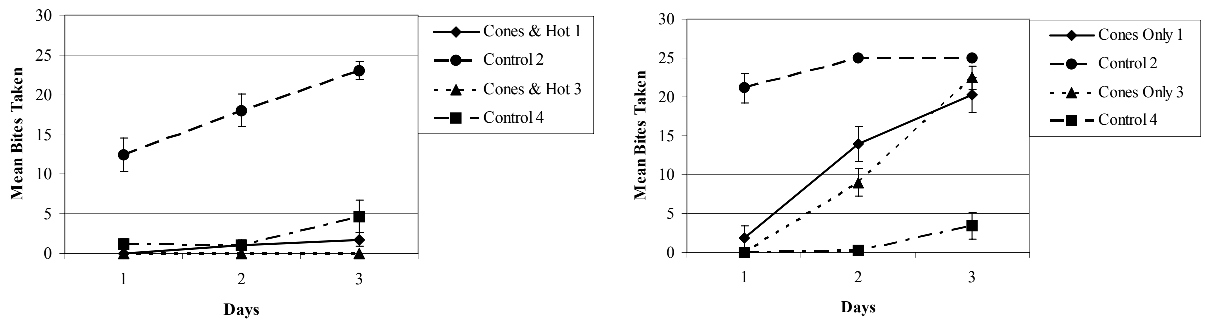


Figure 6. **Mean daily bites taken by deer from plots on pasture A during period 6 (a) and during period (7). Cones and Hot indicates traffic cones were placed around the plot perimeter and the electrical stimulation device was active. Control indicates the plot did not have cones and the electrical stimulation device was either inactive or absent.**



DISCUSSION

Collared deer avoided plots with activated electronic systems. The response was immediate, no training period was necessary. Deer browsed on plot 3 during period 1, browsing then ceased when we activated the plot at the beginning of period 2. This response suggests installing devices on familiar feeding sites may effectively deter deer. Except for one trial, damage in treated areas was non existent. Damage during this trial was minor, and observations suggest it was inflicted by a single deer. Possible explanations for this lapse may have been reduced battery power or a loose collar. When the collar was removed and evaluated after the trial it appeared to function properly, thus we suspect the collar became slightly loose during the trial. The INNOTEK™ owner=s manual cautions that ill fitting collars may hinder efficacy. The collar must be on relatively tight to maintain probe contact with the skin without restricting breathing. A recommended guideline is to tighten the collar until only a single finger can be slid under the strap at the back of the neck.

Our results are similar to trials assessing audio-electric stimulation to deter cattle from protected areas. Quigley and colleagues (1990) trained collared steers to avoid areas by pairing approaches to the area with an audio signal followed by a shock. Subsequently, the audio stimulation alone was adequate to cause steers to turn away from the protected site. They also observed non-stimulated steers to react in conjunction with a partnered stimulated steer, both animals detouring from the site. Ear tags equipped with like technology generated similar results (Tiedemann et al. 1999). Trials demonstrated the devices were about 90% effective at excluding cattle from specific areas, such as riparian zones.

In our study, avoidance of previously treated plots did not persist long after shock devices were deactivated. Although plot 1 was treated with electrical stimulation and surrounded by cones during periods 1 and 2, seedlings were browsed during period 3 after devices were deactivated and cones removed. Deer activity in this plot was less active for the first few days in pasture A, but activity was high by end of the trial. Activity was similar for all untreated plots in Pasture B, regardless of the treatment history. Similar results were recorded when cones depicting treated plots remained in place during period 4. During the prior two periods, cones surrounded the perimeter of plot 3, whenever a deer approached the plot it received a shock. Regardless, deer walked past the cones and began foraging on seedlings in this plot within 24 hours after shock delivery was turned off (Figure 5). These results were repeated during period 7. Although browsing was minimal the day after shock devices were turned off, browsing patterns on the third day did not reflect an avoidance on previously treated plots.

The plot trials indicated deer did not avoid cones previously paired with shock, once shock delivery was halted. Thus, it was not surprising when deer crossed the cone lines stretched across the pastures. However, their behavior suggested they were wary of a possible negative consequence when approaching cones. Prior trials suggested deer may have been testing for the warning tone or shock as they approached plots surrounded by cones, detouring if they were shocked but continuing their approach in its absence. It is possible deer learned to approach cones until they heard the warning tone and then quickly retreated. Our devices did not permit us to maintain the audio warning without shock delivery as demonstrated in the trials with cattle. The quick burst past cones may indicate deer had learned if shock did occur that fleeing from the cones was their means of escape. Similar responses have been observed in trials with deer familiar with electric fences (unpublished data). Deer approaching a fence appeared aware, but willing to undergo the consequence. Although their initial approach might be hesitant (but not always), their approach, when started was deliberate and rapid. This deliberate motion started before the animal was shocked. Studies with dogs have demonstrated that animals may learn to run through a shock in order to escape (Beringer et al. 1994). Increasing intensity of shock causes rats to exhibit more vigorous running into and through the shock field (Sheffield 1949).

MANAGEMENT IMPLICATIONS

Although the systems effectively deterred deer, the current technology probably prohibits operational use of these devices in natural settings to deter deer from target areas. However, a few improvements may render similar devices practical. Battery life is a problem. Collars on dogs can be routinely recharged or new batteries inserted. This routine is not practical with deer. Improved systems that permit remote monitoring or possibly deactivate the electrical stimulation may preserve battery life or at least permit managers to detect ineffective systems. Another problem is irritation caused where the contact probes on collars rub an animal. The INNOTEK™ owner=s manual cautions against prolonged use without removing collars to alleviate possible irritation. This concern could possibly be alleviated by connecting the electrodes to a ring pierced through the animal=s skin rather than probes. Pairing a frightening device located on the target area that emits lights or sounds several seconds before electrical stimulation would probably enhance efficacy, and perhaps preserve battery life. Once the shock was associated with these cues, invading animals may turn away from target areas before the shock is delivered. Similar to the response demonstrated by cattle when the audio warning was emitted (Quigley et al. 1990).

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