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Source: Journal of Vector Ecology, 33(2):325-332. 2008.

Published By: Society for Vector Ecology

DOI: <http://dx.doi.org/10.3376/1081-1710-33.2.325>

URL: <http://www.bioone.org/doi/full/10.3376/1081-1710-33.2.325>

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Reduced interference by gray squirrels with 4-poster deer treatment bait stations by using timed-release bait

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Received 7 April 2008; Accepted 15 September 2008

ABSTRACT: When white-tailed deer, *Odocoileus virginianus*, feed on corn bait dispensed by 4-poster tick control devices, they rub against paint rollers impregnated with acaricide. Gray squirrels, *Sciurus carolinensis*, also feed on the corn bait in the feeding troughs of 4-posters, but in doing so, leave abundant corn fragments and meal that impede the flow of uneaten corn into the troughs. Large accumulations of fragments and meal adversely affect the operation of 4-posters and their use by deer. A battery-operated closure mechanism controlled by a photo sensor was developed to block the flow of corn into the troughs during the day when squirrels are active and deer infrequently visit 4-posters. The effectiveness of the diurnal corn restriction (DCR) concept and restriction mechanism was tested in a field trial at a tick-infested site in Maryland. DCR effectively eliminated accumulation of whole corn, partially eaten corn and corn meal in corn troughs associated with squirrel feeding. At the same time, deer usage of 4-posters was not diminished. *Journal of Vector Ecology* 33 (2): 325-332. 2008.

Keyword Index: White-tailed deer, corn bait, acaricide, blacklegged tick, lone star tick, 4-poster.

INTRODUCTION

The 4-poster Deer Treatment Bait Station (Figure 1) has proven to be an effective technology for reducing populations of the blacklegged tick, *Ixodes scapularis*, and the lone star tick, *Amblyomma americanum*, (Pound et al. 2000a, 2000b, Solberg et al. 2003, Carroll et al. 2003). Both species are of considerable medical and veterinary importance as vectors of the pathogens causing Lyme disease (*I. scapularis*), the human ehrlichioses, and other tick-borne diseases (Sonenshine 1993, Gratz 1999, Childs and Paddock 2003). The white-tailed deer, *Odocoileus virginianus*, is the primary host species of adult *I. scapularis* (Wilson et al. 1985) and is used by all feeding stages of *A. americanum*, especially adults (Patrick and Hair 1978, Bloemer et al. 1988). As deer feed on corn bait dispensed by a 4-poster, they rub against paint rollers impregnated with acaricide, which transfers to their head, ears, and neck, where most adult *I. scapularis* attach (Schmidtman et al. 1998). Because the feeding adults of *I. scapularis* and *A. americanum* are concentrated on deer, targeting deer with an acaricide treatment is a highly efficient way of reducing the reproductive potential of these tick populations.

Raccoons, *Procyon lotor*, and gray squirrels, *Sciurus carolinensis*, also visit 4-posters to feed on corn. Raccoons are hosts for *A. americanum* and *I. scapularis*, and adult American dog ticks, *Dermacentor variabilis*, (Carey et al. 1980, Zimmerman et al. 1988, Fish and Daniels 1990) and

are therefore a secondary target species for 4-poster tick control. Gray squirrels also are hosts of *I. scapularis* and *A. americanum* (Fish and Dowler 1989), and a reduction in tick burdens (nymphs) on squirrels has been associated with proximity to 4-posters⁴.

Gray squirrels interfere with the operation of 4-posters. The quantities of corn eaten by squirrels are negligible compared to that consumed by the principal target species, white-tailed deer, which eat ~0.45 kg corn bait per cwt per day (Pound et al. 1996). Squirrel interference with 4-poster operation arises from the manner in which they eat corn. Although squirrels eat corn spilled on the ground, generally they feed directly from the troughs. Gray squirrels eat corn one kernel at a time, preferentially devouring its endosperm, the central portion of the kernel. If copious whole corn is available to squirrels, they consume the endosperm and discard partially-eaten kernels, usually in and around the feeding troughs. As whole kernels become harder to find, the squirrels feed on the partially-eaten remainders, producing a residue of grits, shell fragments, and meal that gradually fills the feeding troughs (Figure 1).

Where several squirrels and only a few deer use a 4-poster corn remnants accumulate in the troughs. When corn residues become wet from precipitation and saliva,

⁴Abrams, A. 2002. The effect of 4-posters on tick infestations of gray squirrels. MS Thesis, University of Maryland. 97 pp.

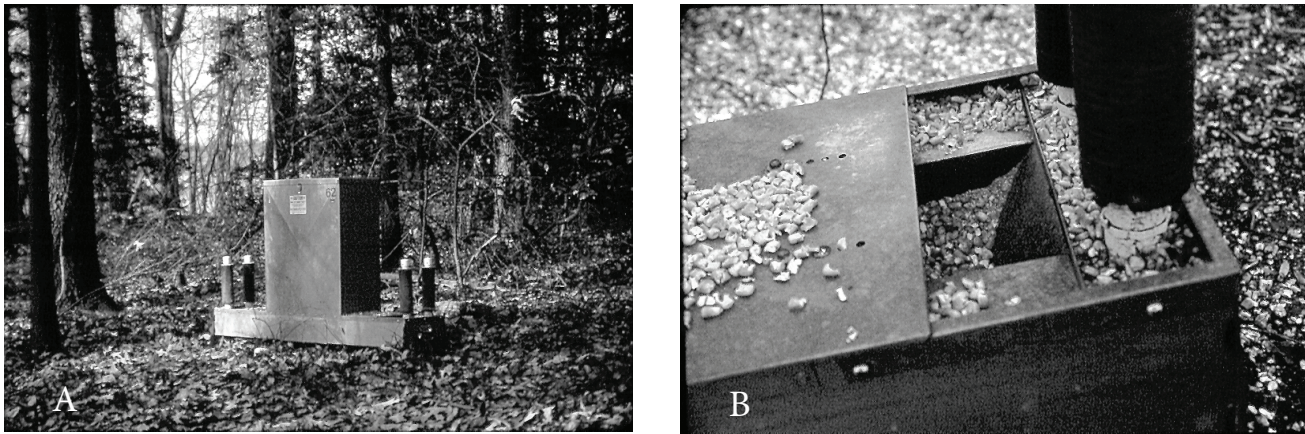


Figure 1. (A) Operational 4-poster. Note large central storage bin and acaricide-impregnated paint rollers. (B) One of two feeding troughs of a 4-poster with evidence of squirrel feeding. Note partially eaten corn kernels, crumbs, and meal in and around the trough. Accumulations of corn fragments and meal can obstruct the flow of corn from the storage bin to the troughs, especially during wet conditions when fungi and bacteria can flourish.

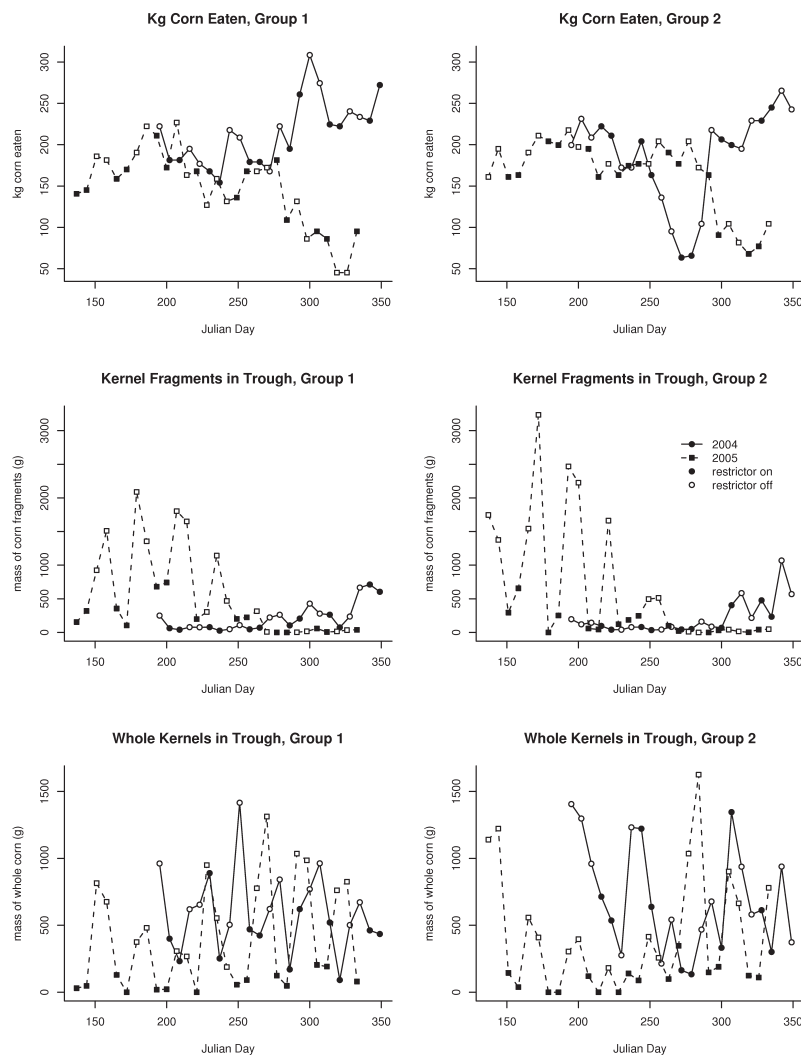


Figure 2. Two groups of 4-posters were operated simultaneously, but on alternate schedules (when one group had corn diurnally restricted, the other had corn continuously available). Weekly corn consumption was little affected by DCR. Corn was collected once per week (mornings in 2004, early afternoons in 2005) from the troughs of the 4-posters. In 2005, when corn was collected after squirrels had several hours to feed, quantities of whole corn and corn fragments and meal from the troughs from 4-posters with diurnal restriction were smaller than those with the restrictor mechanism inactivated.

they can fuse into a mass that blocks the flow of whole corn into the troughs. Although there are drain holes in the floor of each trough, prolonged wetness of the residue leads to fungal and bacterial growth, further occluding the flow of corn and discouraging deer feeding. In warm weather, occluded corn tends to germinate quickly when wet. Weekly servicing (replenishment of corn and acaricide) of 4-posters is recommended, but observations by JFC at GSFC and elsewhere in Maryland (Carroll et al. 2003) suggest that even within this restricted time frame, feeding by several squirrels can reduce or neutralize the efficacy of a 4-poster.

The contrasting daily activity patterns of white-tailed deer (nocturnal, crepuscular) and squirrels (diurnal) present an opportunity for mitigating the squirrel problem without diminishing 4-poster efficacy. The greatest impact of 4-posters on tick populations is obtained by treating adult ticks before they reproduce. It is preferable to treat deer (carrying adult ticks) and discourage squirrel usage. Here we describe a photo-controlled mechanism that prevents corn from flowing from a 4-poster's central storage bin into its feeding troughs during the day when squirrels are active but allows corn to flow when deer are most active, from dusk to dawn. We evaluated the effectiveness of the diurnal corn restriction (DCR) concept using 4-posters in a field study.

MATERIALS AND METHODS

Study area

In 2004 and 2005, ten 4-posters retrofitted with corn restriction mechanisms were deployed at the U. S. National Aeronautic and Space Agency, Goddard Space Flight Center (GSFC), Greenbelt, MD, where 4-posters were already in use to control *I. scapularis* and *A. americanum*. All 4-posters in the study areas were replaced with retrofitted ones and the remaining retrofitted devices were placed in new locations on the GSFC site. The 4-posters were divided into two groups of five devices. In 2004, one group of 4-posters was operated on the fenced East Campus of GSFC and the second group split among the fenced West Campus (two devices), the fenced Area 200 (two devices), and a peripheral location on the East Campus (one device) to minimize interaction with 4-posters in the first group. The following year, one group of devices was on the East Campus, and the second group was divided between the West Campus (two devices) and Area 200 (three devices). On the West Campus, 4-posters had been in operation for about ten years (Solberg et al. 2003) and on the East Campus for five years⁴. Deer populations were estimated to be 15, 50, and 25 deer on the West Campus, East Campus, and Area 200, respectively, based on corn consumption from 4-posters (J. M. Pound, unpublished data) and from annual walking drive-line censuses on the West Campus (led by L. Adams, University of Maryland, College Park, MD).

Corn restriction

The modified 4-posters were constructed of sheet metal (Pound et al. 2000a). The corn restriction system

consisted of a photo-controlled motor powered by a 12 v sealed rechargeable battery (Vision CP1272, Center Power Tech Co., Ltd., Shenzhen, China) that operated a cable that opened and shut two vertical sheet metal plates (shutters), each set to occlude the corn flow into one of the two feeding troughs between dawn and dusk. No artificial lighting was close enough to any 4-poster to influence the operation of its photo sensor.

Adhering to the schedule of the GSFC tick control program, the 4-posters went into operation in March with no corn restriction. Each roller of each device was treated weekly with 5-40 ml 10% permethrin, Brute®, according to the quantity of corn consumed during the previous week. In July, 2004 and May, 2005, batteries were installed in one group of 4-posters and the restriction mechanisms in these devices were operated for two weeks. Corn was available *ad libitum* from the other group of 4-posters during the same two week period. The storage bin of a 4-poster held 133 kg of corn, so an effectively limitless supply of corn was available *ad libitum* to deer, raccoons, and squirrels, which were not abundant.

At the end of the two-week period, batteries were removed from the first group of 4-posters for recharging, and a second set of batteries was placed in the other group of 4-posters. Corn restriction and *ad libitum* availability were alternated between the two groups of 4-posters at two-week intervals until December, when low temperatures suppressed host-seeking by adult *I. scapularis* and 4-poster operation was suspended. The strategy of alternation was used so that within 4-poster comparisons could be made, since total yearly amounts of corn eaten within 4-posters would differ due to varying deer use.

Corn was replenished and acaricide applied to the rollers weekly. Extra-clean (dust-free) corn is needed for optimal functioning of 4-posters, but the cleanliness of bagged corn can vary. Dusty corn fosters internal blockages in 4-posters, particularly in high humidity. To ensure the flow of corn from the storage bin into the troughs, the ducts connecting the storage bin to the troughs in each 4-poster were probed with a bent steel rod two or three times weekly. Little new corn was added to the trough during this process.

One 4-poster was equipped with four HOBO Event Loggers™ (Onset Computer Corp., Bourne, MA) that recorded every deflection of each of the four posts supporting the acaricide-impregnated paint rollers. Mammalian and avian feeding activity at this logger-equipped 4-poster was continuously monitored using a solar-powered Panasonic (Secaucus, NJ) WV-BBL602 closed circuit television camera augmented by a Dark Invader Owl infra red night vision system (B. E. Meyers, Inc., Redwood, WA) and a time-lapse video recorder (GYR, Odetics, Anaheim, CA) mounted on a trailer. Each of four small (1 cm diam) red lights mounted on the side of the 4-poster corn bin that faced the video camera was connected to a post and flashed once for each deflection of its post. Each contact with a roller sufficient to cause a deflection was confirmed on the videotape recording. Numbers of deer, squirrels, raccoons, opossums, *Didelphis virginianus*, and Canada geese, *Branta*

canadensis, and times of day they were within ~1.5 m of the 4-poster were recorded. To corroborate the seasonal pattern of squirrel activity at the videotaped 4-poster, squirrel activity at other 4-posters was also monitored by recording the numbers observed within ~2 m of a 4-poster on visits to replenish corn and acaricide from late June through November, 2005.

Corn consumption

Weekly corn consumption from each 4-poster was determined from changes in the level of corn measured on a vertical linear gauge magnetized to the inner wall of the storage bin and calibrated to indicate the weight of the corn in 4.5 kg increments. Corn in the troughs was collected weekly between ~07:30-10:00 h in 2004 and ~13:00-14:30 h in 2005, air dried if it rained during the preceding 24 h, and weighed. Because fragmented corn indicated squirrel feeding, trough corn from each 4-poster was then sifted through a 0.6 cm mesh screen, separating whole corn and large fragments from small fragments and meal. Each fraction was weighed.

Statistical methods

To determine the effect of DCR on the weight of whole corn fractions and remnant fractions left in the trough, we used two-sided non-parametric Mann-Whitney U tests for unpaired weekly samples, where weekly samples were grouped by DCR status, and tested each 4-poster separately. We assume that the weekly weights are uncorrelated because all remaining corn and fragments in the troughs of the 4-posters were removed for weekly measurement. With regular nightly deer feeding and no squirrel interference, the corn in the troughs was largely or completely replaced daily. Thus, the weekly trough corn measurement can be envisioned as that corn left in the trough following the most recent deer visit minus the amount removed by any subsequent squirrel feeding. A non-parametric test was used because the data were highly skewed, especially in 2005.

The assumptions for parametric modeling were better met by the consumption (kg eaten) data. We also wanted a more powerful test to detect any effect of DC on deer usage since regular use of the 4-posters by deer is Cessential for the tick-reduction program.

To determine if there was a DCR effect on consumption (kg eaten), to each 4-poster, we fit a reg-ARIMA model (regression allowing for time series correlated errors). Models were fit separately to each 4-poster because usage patterns among the 4-posters by deer clearly differed. A model encompassing all 4-posters would have required interaction terms involving 4-poster identity, and thus be more difficult to interpret. The regression consisted of a linear weekly effect (consumption generally decreased over the data collection season in 2005) and a (0-1) dummy variable to capture the DCR effect. The ARIMA part was represented as an MA(1) (one parameter moving average model) which captured the time series correlation structure of the residuals (sequential weeks tended to have similar consumption amounts, after allowing for the DCR and week

effects). An MA(1) was chosen because it generally yielded a lower AIC (Akaike's Information Criterion) (lower implying better fit) than the other ARIMA models tried, AR(1) (one parameter autoregressive model) and ARMA(1,1) (AR(1) + MA(1), so a two parameter model).

We used Pearson correlation statistics to determine if there was a significant linear relationship between deflections and consumption or number of deer present for the one 4-poster measuring deflections. All statistics were calculated using the R software (R Development Core Team Vienna, Austria. ISBN 3-900051-07-0, <http://www.R-project.org>).

RESULTS

Corn consumption

For nine of ten 4-posters in 2004 and eight of ten in 2005, average weekly corn consumption was less when the restriction mechanism was operational than when corn was continuously available. However, this difference was not statistically significant (*t*-test on the dummy variable indicating DCR status, $P > 0.05$, 12 df) for all the 4-posters in 2004 and for nine of the ten 4-posters in 2005. Figure 2 depicts the means for the two groups of 4-posters with asynchronous DCR status.

DCR affected total trough corn and amount of corn fragments, including meal. High levels of total corn and corn fragments in the troughs are indicators of squirrel feeding. In 2005, when trough data were collected in the early afternoon, for seven of ten 4-posters, the weight of corn fragments and meal collected weekly from the troughs of restricted 4-posters was significantly less (Mann-Whitney U test, $P < 0.05$) than when corn was continuously available, whereas in 2004, when trough corn was collected early in the morning, there was a significant difference (Mann-Whitney U test, $P < 0.05$) for only one 4-poster. In 2005, significantly less (Mann-Whitney U test, $P < 0.05$) whole corn, including large corn fragments retained by the sieve, was collected weekly from the feeding troughs from all the 4-posters when corn was restricted diurnally than when corn was available *ad libitum*, but in 2004 there was a significant difference for only one 4-poster. Thus, in 2005, DCR reduced the amount of both whole corn and corn fragments from accumulating in the troughs. Because the early collection times (sometimes only ~1 h after dawn) in 2004 gave squirrels little opportunity to visit the 4-posters, we were unable to detect the effect of DCR on trough corn in 2004.

Activity

Shade from the forest canopy and space limitations for the solar-powered video trailer allowed continuous videotaping at only one 4-poster. However, videotape records over two years provided insights into the activity patterns of deer, squirrels, raccoons, and geese at this device. Counts of squirrels made as we approached 4-posters for servicing and corn collection from late June through August, 2005, show that the numbers of squirrels within 2 m of the videotaped

4-poster were similar to those for the other 4-posters on the East Campus. An average of 1.07 ± 0.16 (SE) squirrels per observation ($n = 41$) was within ~ 2 m the videotaped 4-poster and 0.66 ± 0.15 , 0.76 ± 0.15 , 1.05 ± 0.20 and 0.66 ± 0.14 squirrels at the other 4-posters.

Videotape records of deer activity at the 4-poster with the event recorders revealed no obvious impact of operational status. The activity patterns for deer, squirrels and raccoons over the same four-week period (two consecutive two week periods with and without DCR) are shown in Figure 3. Data for other periods (not shown) also did not show any impact of restricted or unrestricted corn availability.

We defined deer-hours, for a given time period, as the number of deer multiplied by the length of their stay (in hours) at the 4-poster (e.g., two deer staying 30 min at the same time total one deer-hour). When two-week total deer-hours for the videotaped 4-poster are graphed, no pattern attributable to DCR status is evident (Figure 4). Squirrel-hours (defined similarly) were in the hundreds per two-week period in the spring and early summer of 2005, but overall there was no pattern in squirrel-hours related to DCR status (Figure 4).

When corn flow was restricted at dawn, varying amounts of corn, one to several kernels deep (a 2-cm layer of whole corn bait weighed ~ 170 g), were in the troughs. Squirrel activity at 4-posters did not cease when corn was restricted, but their afternoon activity diminished as they consumed the residual corn (more notably in 2005) (Figure 3).

As documented in videotapes of the 4-poster equipped with event recorders, squirrel activity in 2004 declined in mid-August and rebounded by October. From mid-September through November 2005, squirrel activity at the videotaped 4-poster was much lower and fewer squirrels observed when we serviced all the 4-posters compared to earlier in the year. These periods of limited use of the 4-posters by squirrels coincided with acorn maturation and drop.

Numbers of deflections per week of the posts bearing the acaricide-impregnated paint rollers did not differ significantly ($t = 0.15$, $P > 0.50$, 12 df) between periods when corn was restricted and when it was continuously available. In the fall, corn consumption decreased, yet weekly total deflections (hundreds to thousands) indicated that deer using the 4-poster were still adequately treated with acaricide. Deflections were more closely correlated ($r = 0.4562$, $t = 2.235$, $P = 0.037$, 19 df) with the weight of corn eaten than with deer-hours at the 4-poster ($r = 0.3145$, $t = 1.406$, $P = 0.177$, 18 df). The amount of corn eaten per deer-hour at the 4-poster is shown in Figure 5. In 2005, there was a downward trend in kilograms of corn eaten per hour during the study period when corn was continuously available (i.e., for visits of the same duration, deer consumed less corn later in the year) until the final two weeks when there was a sharp increase both years.

Raccoons used the videotaped 4-poster more in the late spring-early summer than late summer-early fall, and the frequency of their visits did not appear to differ due to

DCR status (Figures 3 and 4). Geese visited the videotaped 4-poster frequently during an approximately one-week period in the late summer of 2004 and \sim two weeks in the late spring of 2005. Although locally abundant, opossums were rarely recorded on the videotape.

DISCUSSION

An important outcome of this evaluation was determining that the reduction of squirrel interference with 4-posters did not compromise deer usage of the devices. Large reductions in weekly corn consumption from diurnally restricted 4-posters would have strongly suggested that deer feeding was inhibited by diurnal corn restriction. Instead, there was no significant difference in weekly corn consumption between restricted and *ad libitum* 4-posters. A second indication that deer usage of 4-posters was not altered by DCR was that it did not appear to reduce deer visitations at the videotaped 4-poster. A third indication that deer usage was not substantially changed when corn was diurnally restricted was that the weekly number of deflections of the acaricide-impregnated paint rollers was correlated with corn eaten (the latter not affected by DCR status). As long as deer use the 4-posters regularly, small differences in the amount of corn consumed due to DCR status are not important. The autumnal decline and eventual rebound in the amounts of corn eaten per deer likely reflects acorn abundance and depletion.

The number of blockages of the corn flow into the troughs on DCR and *ad libitum* 4-posters would seem to be an ideal criterion for and a means of quantifying the efficacy of DCR. However, blockages arise not only from excessive squirrel feeding but from other sources as well. Dusty corn fosters blockages in the bin, ducts and apertures to the troughs, and troughs. Blockages can start in the troughs and by mold growth spread internally and vice versa, making it difficult to determine whether the blockage was due to squirrel feeding. A more reliable measure of the effectiveness of corn restriction on squirrel interference with 4-poster operation was the quantity of whole and fragmented corn and meal accumulated in the troughs in the afternoon, after the squirrels had a few hours to feed following the corn flow stoppage in DCR 4-posters at dawn.

The discrepancy between the 2004 and 2005 data for trough corn can be explained by the time of day when the corn was collected from the troughs. In 2004, we collected corn from the troughs in the morning 07:30-10:00 h. Thus, in the fall of 2004, the first collections of the day were only ~ 1 h after dawn allowing squirrels little time to feed at the 4-posters before the trough corn was collected. In 2005, when the trough corn was collected in the early afternoon, there was significantly less corn in the troughs of diurnally-restricted 4-posters than in the unrestricted devices. Videotape recordings corroborated that, when corn was restricted, squirrel activity at the 4-poster dwindled as afternoons progressed. Reduced squirrel consumption of corn should result from DCR, but even where squirrels were numerous at a 4-poster, the quantities of corn eaten

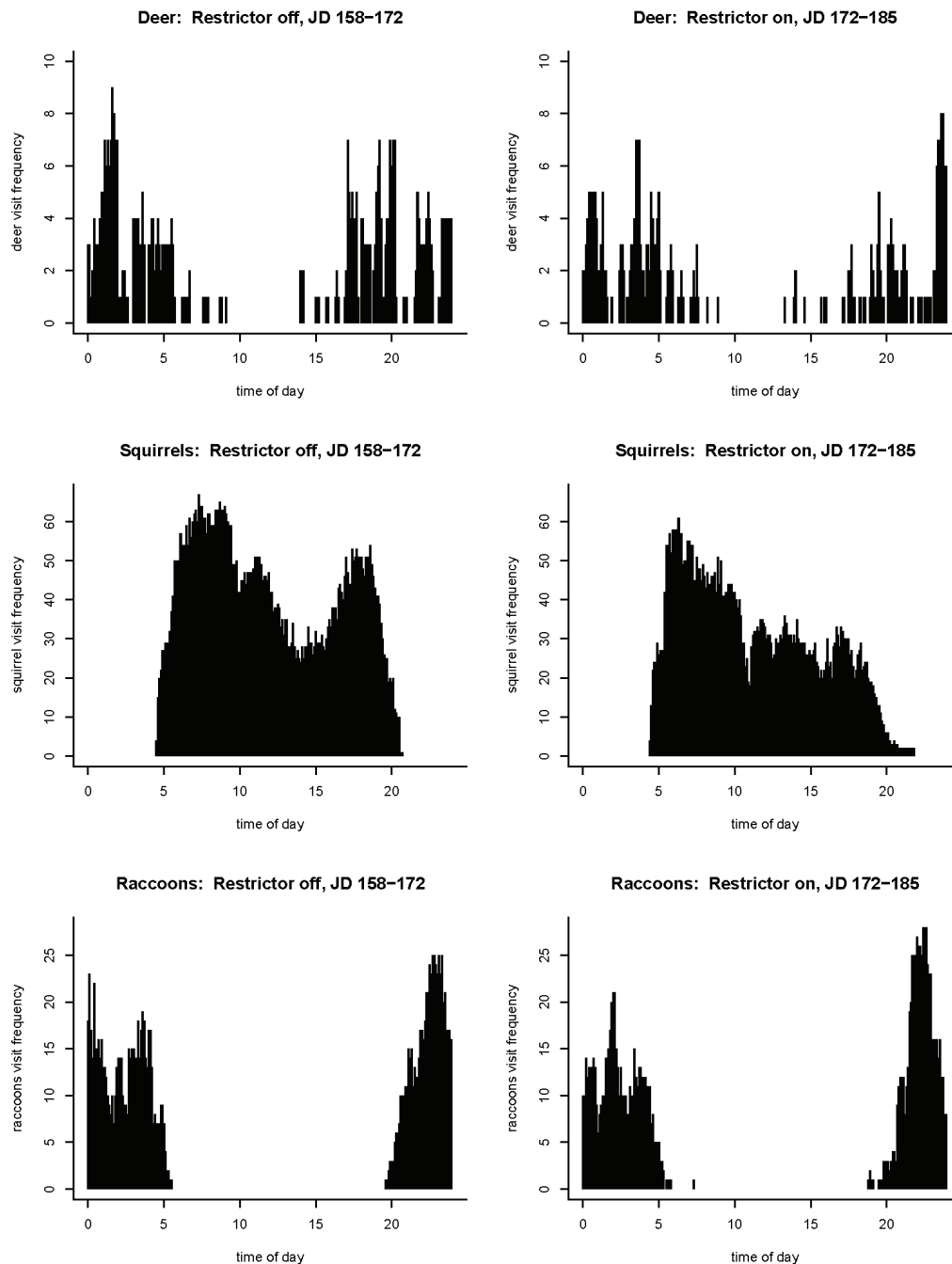


Figure 3. The temporal activity patterns of deer, squirrels and raccoons at a 4-poster based on continuous time-lapse videotapes are depicted for two two-week periods in June-July, 2005. Corn was diurnally restricted (restrictor on at 5:45 and off at 20:35) on Julian days (JD) 172-185 and continuously available (restrictor off) JD 158-172. Note decreased frequency of squirrel activity during the afternoons when corn was restricted compared to when corn was available. During these time periods the sun rose at 5:40-5:45 and set at 20:31-20:36 EDT.

were negligible compared to amounts eaten by deer.

Videotape records showed that raccoons were regular nocturnal visitors (except August to October, 2005) at the 4-poster equipped with event recorders. Matching of flashes from the red lights on the side of the 4-poster that were recorded on videotape with deflections recorded at the same time confirmed that raccoons solidly contacted the paint rollers.

In 2005, geese regularly fed at the videotaped 4-poster

from the first recordings in May until three days after the start of the first corn restriction period for that device later that month. As many as ten geese were recorded simultaneously at or near the 4-poster. Thus, DCR also seems to limit corn consumption by geese to residual amounts in the troughs and corn spilled on the ground.

A potential consequence of discouraging squirrel activity at 4-posters is a reduction of exposure of squirrels to the acaricide. Abrams⁴ found the numbers of *A. americanum*

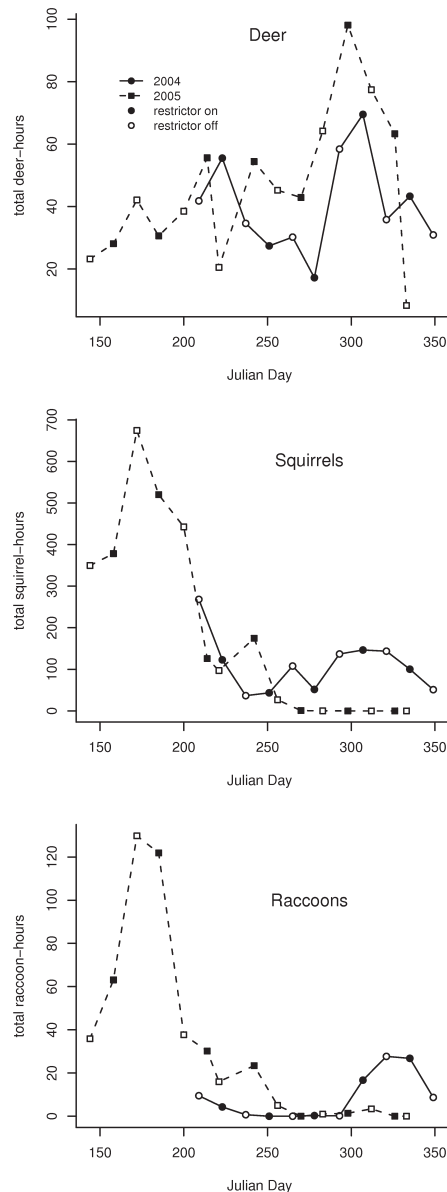


Figure 4. Total deer-, squirrel-, and raccoon-hours per two-week period, with no obvious pattern related to the restrictor status of the videotaped 4-poster. Note that scales differ for each plot, also the intense use of the 4-poster by squirrels early in 2005.

and *I. scapularis* on squirrels captured <10 m from 4-posters to be lower than on squirrels ≥ 200 m from the devices, though it was not established that this difference was due to acaricidal treatment of squirrels. Observations and videotape records, however, show that squirrels fed from the troughs with little solid contact with the paint rollers. This was substantiated by the absence of flashes from the red lights on the 4-poster and the lack of deflection events when only squirrels were at the videotaped 4-poster. Light contact of squirrel pelage with rollers was possible.

LoGiudice et al. (2003) considered gray squirrels to be "dilution hosts" in the ecology of Lyme disease that reduce infection prevalence from what it would be if ticks were

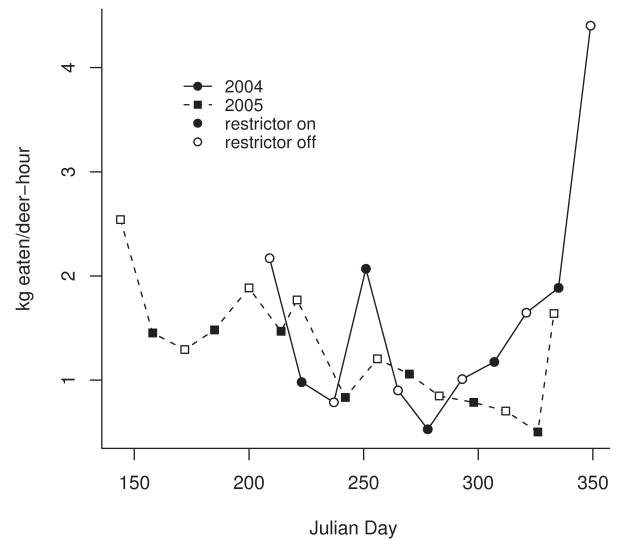


Figure 5. For the videotaped 4-poster, the quantity of corn eaten/deer-hour trended lower over time in 2005, whereas in 2004 there was no pattern evident. Fawning in late spring and the mating season in the fall may influence the feeding habits of deer at 4-posters. Note the sharp rise in consumption/deer-hours that occurred in the last period each year for unknown reasons.

feeding solely on the principal reservoir species, white-footed mice, *Peromyscus leucopus*. Failure to expose squirrels to the acaricide would allow squirrels to retain their role as a "dilution" host for Lyme disease, whereas effective acaricide treatment of squirrels would diminish the density of the tick population in a small way. In the United Kingdom, where gray squirrels are an introduced species, Craine et al. (1997), reported they are reservoir and amplifying hosts of the causative agent on Lyme disease.

This study demonstrates that preventing squirrels from feeding *ad libitum* on the corn bait in the troughs of 4-posters by DCR minimizes conditions that predispose development of corn blockages and reduced 4-poster efficacy. The use of a 4-poster by a large number of deer counteracts the effects of squirrel feeding. However, where squirrels are abundant and deer numbers low to moderate, it may be practical to use a 4-poster equipped for DCR.

Acknowledgments

We thank Darlene Squibb, National Aeronautics and Space Agency, Goddard Space Flight Center, Greenbelt, MD, for her cooperation in coordinating this study with environmental programs and policies at GSFC. We are grateful to Kenneth W. Young, Hasani Martin, and Michael Theis, USDA, ARS, Animal Parasitic Diseases Laboratory, Beltsville Agricultural Research Center, Beltsville, MD, for their efforts in maintaining and operating 4-posters and video equipment. We express our gratitude to Wayne Ryan and Gary Earl, USDA, ARS, Knippling-Bushland U. S. Livestock Insects Research Laboratory, Kerrville, TX,

for retrofitting 4-posters with corn restriction systems and providing guidance on their use and maintenance. We extend our appreciation to Art Abrams, USDA, ARS, Animal Parasitic Diseases Laboratory, Beltsville Agricultural Research Center, Beltsville, MD, for his valuable insights on squirrel behavior. We also thank Kendesi Mohammed, Harold Lofton, Scott Painter, Dennis Braden, Lorenzo Brown, Frank Budd, Douglas Traynham, and Jessie Wedge, Melwood, Inc., Upper Marlboro, MD, for replenishing corn in the 4-posters.

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