Influence of Deer Exclusion on Populations of Lone Star Ticks and American Dog Ticks (Acari: Ixodidae)

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ABSTRACT A 2.43-ha deer exclosure was constructed in the Tennessee Valley Authority's Land Between The Lakes in 1977-78 to study the effects of deer exclusion on the lone star tick, Amblyomma americanum (L.). Tick populations were monitored with dry ice in 1978 and 1979, and with dry ice and drags in 1982. Lone star tick larvae averaged 98% fewer on exclosed plots than on control plots for all 3 study years. Populations of overwintered nymphs and adults were reduced by acaricide application and showed no significant differences in 1978. For 1979 and 1982, nymphs averaged 38% fewer on exclosed plots. Adults averaged 22% fewer on exclosed plots for 1979 and 1982; however, this difference was not significant. Reinfestation of the exclosure by adults and nymphs was attributed to movement of small host animals between the exclosed and adjacent untreated areas. A possible exclosure response was also observed in the American dog tick, Dermacentor variabilis (Say), in that the exclosed field became more infested with adult American dog ticks than the other areas.

The lone star tick, Amblyomma americanum (L.), has become a serious problem in recent years in areas of Kentucky and Tennessee, along with other areas in the Southeast. This tick is an annoying pest and a vector of organisms pathogenic to humans, domestic animals, and wildlife. All three stages of the lone star tick parasitize man and a wide variety of other animal hosts (Cooley & Kohls 1944, Bishopp & Trembley 1945, Clymer et al. 1970, Koch & Dunn 1980). Several authors have reported, however, that adult lone star ticks feed primarily on larger host animals, particularly cattle and deer (Clymer et al. 1970, Cooney & Burgdorfer 1974, Barnard 1981).

The association between white-tailed deer, Odocoileus virginianus (Zimmerman), and lone star ticks has been well documented. Patrick (1976) reported that white-tailed deer serve as hosts for all three stages of the lone star tick and would appear to have the greatest impact of any host on the abundance of the tick where cattle were not abundant. In a survey of ticks infesting white-tailed deer in 12 southeastern states, the lone star tick was found on deer in all states surveyed (Smith 1977).

The possible effect of a reduced deer population on lone star ticks was described by Patrick & Hair (1977). They suggested that a decrease in the deer population on their study area in Oklahoma may have caused a decrease in lone star ticks. The purpose of the present study was to document the effects of deer exclusion on a lone star tick population in western Kentucky, and note any accompanying changes in populations of American dog ticks, Dermacentor variabilis (Say).

Materials and Methods

The study site was located in the Tennessee Valley Authority's Land Between The Lakes (LBL), a national demonstration and recreation area in western Kentucky and Tennessee. The LBL peninsula contains 68,800 ha of predominantly upland oak/hickory hardwood forest and was described geographically by Cooney & Burgdorfer (1974). In the winter of 1977-78, a 2.43-ha deer exclosure was built in a secluded area in the north end of LBL. The exclosure fence consisted of two runs of standard woven wire hog fencing attached one above the other on wooden posts. The bottom strand of woven wire was inverted to put the large openings (20.3 by 15.2 cm) at ground level, thereby allowing access to smaller mammals. The fence height was 2.4 m. The exclosed area was approximately square, half in mature upland oak/hickory hardwood forest and half in a reverting field. The field had been maintained in an early successional stage by mowing once every 4 years as part of a wildlife management program. The field was characterized by broomsedge, Andropogon virginicus L.; sumac, Rhus spp.; blackberry, Rubus spp.; and honeysuckle, Lonicera japonica Thunb., with vegetation not exceeding 1 m in height at the time of exclosure construction. The control area was adjacent to the exclosure in continuous habitats. Effective deer exclusion commenced 1 February 1978. Chlorpyrifos was applied to exclosed and control areas on 28 March 1978 to kill over-
wintertined nymphs and adults that were carried into the area before exclosure construction. Application was made with an all-terrain, orchard-type sprayer (Solo Model 454) at the rate of 0.28 kg (AI)/ha solution.

White-tailed deer populations were estimated for this study using Program ONEPOP, a big game population dynamics model. The model had been previously established for estimating LBL deer populations. The model was based on 10 years of harvest age and sex data, and estimated parameters including natural mortality, wounding loss, and reproductive rates. For the present study, only data for a 4,100-ha hunt area in which the exclosure was located were used in the model because deer population levels were being manipulated differently in adjacent areas.

To estimate tick numbers, nine plots (30.5 by 15.2 m) were uniformly spaced in each area: exclosed woods, exclosed field, control woods, and control field. Plots were at least 15.2 m from the exclosure fence; they were sampled using a dry-ice technique adapted from Grothaus et al. (1976). A white nylon cloth (1 m²) with a 0.45-kg block of dry ice on it was placed in the center of each plot. One hour later, ticks on both sides of the cloth were identified, counted, and returned to the plot. Samples with dry ice were taken weekly in 1978 and 1979. In 1982, two 30.5-m drag transects were established in each habitat in the exclosed and control areas to better monitor larval populations. Transects were sampled by dragging a 1-m² white flannel cloth at the side of the collector. Samples with dry ice and drags were taken every 2 weeks during the 1982 season.

Tick data were analyzed using the Statistical Analysis System (SAS Institute 1982). Weekly samples in 1978 and 1979 were averaged for each plot to provide a biweekly mean for comparison with 1982 data. Henceforth, biweekly intervals will be referred to as periods. Data from previous research (unpublished data) have shown that the majority of ticks are collected with the above sample methods at LBL during the following time intervals:

- April through 30 June for adult lone star ticks,
- 15 April through 1 August for nymphs,
- 1 August through 15 October for larvae, and
- 10 June through 20 August for adult American dog ticks.

Therefore, only data collected during those intervals were used in statistical analyses; at other times, low numbers collected may have been insufficient for determining possible differences.

Means and standard deviations of tick samples were proportional, and linear regressions fitted to the means and standard deviations had significant slopes. The proportionality indicated a need for a logarithmic transformation (Steel & Torrie 1960) and, since zero counts were not uncommon, a log (x + 1) transformation was used. The dependency of the standard deviation on the mean was dramatically reduced following the transformation. The log transformed data were then analyzed as a multifactor repeated measures design (Winer 1971), often referred to as a "split plot in time" in agricultural experiments. The experiment had four factors (habitat, exclosure, period, and year). The experimental units were nine plots uniformly spaced over each habitat inside and outside the exclosure. When significant interaction existed between two or three main-effect factors, multiple comparison procedures as outlined in Winer (1971) were used to analyze differences that characterized the interaction. These procedures were reduced to t tests when there were two levels of factors to compare. In the pairwise comparisons, error sums of squares from the analysis of variance were pooled as in Winer (1971), and the degrees of freedom from the sample size were large enough to use the standard normal critical value. Data from drag samples were analyzed in the same manner.

### Results

On rare occasions, fallow deer, *Dama dama* (L.), were observed in the vicinity of the exclosure; however, their numbers were believed to be very few relative to white-tailed deer numbers. Routine examination of the exclosed area for evidence of deer entry (tracks, droppings, or browsed vegetation) verified that the exclosure fence was an effective deer barrier. From 1973 through 1979, the estimated postfawning white-tailed deer popula-

### Table 1. Effects of 28 March 1978 acaricide applications on overwintered lone star tick populations (± SD, n = 9)

<table>
<thead>
<tr>
<th>Life stage</th>
<th>Control Woods</th>
<th>Control Field</th>
<th>Exclosure Woods</th>
<th>Exclosure Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preacaricide (23 March)*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adults</td>
<td>46.1 ± 25.5</td>
<td>50.8 ± 37.0</td>
<td>92.4 ± 44.3</td>
<td>31.6 ± 21.5</td>
</tr>
<tr>
<td>Nymphs</td>
<td>54.3 ± 112.6</td>
<td>11.3 ± 5.9</td>
<td>49.6 ± 65.1</td>
<td>50.1 ± 97.2</td>
</tr>
<tr>
<td>Postacaricide (4 April)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adults</td>
<td>0.1 ± 0.3</td>
<td>0.2 ± 0.7</td>
<td>0</td>
<td>0.4 ± 0.5</td>
</tr>
<tr>
<td>Nymphs</td>
<td>4.1 ± 10.5</td>
<td>4.3 ± 6.7</td>
<td>5.8 ± 12.2</td>
<td>6.7 ± 5.6</td>
</tr>
</tbody>
</table>

*No American dog ticks or larval lone star ticks were collected.*

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ordinarily are not collected with dry ice at that time of year. Acaricide was applied on 28 March, resulting in a substantial reduction in numbers of overwintered lone star ticks (Table 1).

Mean numbers of lone star ticks per sample on exclosed and control plots are presented for each study year in Fig. 1. Data include ticks collected with dry ice from 1 April through 15 October. Adult lone star ticks were fewer in 1978 than in 1979 or 1982 as a result of the acaricide application ($F = 251; \text{df} = 64; P < 0.01$). Exclosed plots averaged 25% fewer adults than control plots in 1979, and 18% fewer in 1982, but these differences were not significant ($F = 2.08; \text{df} = 32; P \approx 0.16$).

The importance of habitats changed for adult lone star ticks from 1979 to 1982. In 1979, more adults were found on plots in wooded habitats than in field habitats ($t = 6.7; P < 0.01$). By 1982, the field habitats had become densely vegetated as a result of natural succession. In 1982, more adults were found on plots in the field habitats than in the wooded habitats ($t = 4.48; P < 0.01$). It is important to note that mean numbers of adult lone star ticks per sample decreased more rapidly on control plots than on exclosed plots. This trend was clearly illustrated in wooded habitats in 1979 (Fig. 2). Although the seasonal mean for adults in the control woods versus exclosed woods in 1979 (Fig. 1) showed only a 2% difference (9.4 adults per sample versus 9.2 adults per sample), there was a 20% difference on the first sample of the overwintered population in early April (45.2 adults per sample versus 36.2 adults per sample). The higher initial numbers, accompanied by a faster rate of decline, resulted in a seasonal mean for the control woods similar to the seasonal mean for the exclosed woods, which had lower initial numbers but prolonged host-seeking activity. Likewise, plots from the exclosed field averaged 71% fewer adults than plots from the control field on the first sample in 1979, while the season average was 58% fewer.

Nymphal lone star ticks were fewer in 1978 as a result of the acaricide application ($F = 144; \text{df} = 64; P < 0.01$). For 1979 and 1982, exclosed plots averaged 38% fewer nymphs than control plots ($F = 5.90; \text{df} = 32; P \leq 0.06$). As with adults, there were even greater differences on early samples of the overwintered population, but numbers de-
creased more rapidly on control plots (Fig. 3). The numbers of nymphs collected in wooded habitats were not significantly different from numbers collected in field habitats in 1979 and 1982 (F = 0.50; df = 32; P = 0.48).

Larval lone star ticks collected with dry ice were significantly fewer in 1982 than in 1978 or 1979 (F = 11.8; df = 64; P = 0.01). Larval ticks aged 98% fewer on exclosed plots than on control plots for all 3 study years. In 1978, differences in means were significant between control and exclosed field plots (t = 2.94; P < 0.01), and between control and exclosed woods plots (t = 4.87; P < 0.01). In 1979, there was a significant difference between control and exclosed woods plots (t = 7.80; P < 0.01), but not between control and exclosed field plots (t = 0.80; P ≥ 0.42). In 1982, the low numbers of larvae collected with dry ice were not significantly different on exclosed versus control plots in wooded habitats (t = 0.04; P ≥ 0.97) or field habitats (t = 1.32; P ≥ 0.19). Means and standard errors (n = 16) of larval ticks per drag sample in 1982 were: control woods, 71.2 ± 32.2; exclosed woods, 0.6 ± 0.4; control field, 4.4 ± 3.5; and exclosed field, 0.7 ± 0.4. Larvae were 98% fewer on drag samples inside the exclosure compared with outside in 1982, however, because of small sample size and high standard errors, the difference was not significant (P = 3.39; df = 4; P ≥ 0.14).

Numbers of American dog ticks from samples with dry ice are presented for each year in Table 2. In 1978, 1979, and 1982, adult American dog ticks were respectively 27, 41, and 66% fewer on exclosed plots than on control plots. Significant differences occurred between the field habitats during 1979 and 1982. In 1979, the control field averaged 71% fewer American dog ticks per sample than the exclosed field (t = 3.04; P < 0.01). In 1982, 73% fewer American dog ticks were collected in the control field than in the exclosed field (t = 3.24; P < 0.01). Differences in numbers of American dog ticks were not significant in any year on plots in the exclosed woods versus control woods (t = 0.13, 0.27, 0.58; P ≥ 0.90, 0.79, 0.56, respectively).

### Discussion

The fence built for this research effectively excluded deer from a 2.43-ha area containing an old field and upland oak/hickory hardwoods. Habitats in the exclosure were continuous with those outside. Observation of small mammal tracks, pathways, and the mammals themselves indicated that small mammals (including rabbits, raccoons, and foxes) had little difficulty crossing through or under the exclosure fence. The minimum distance between the fence and sample plots was 15.2 m and ticks were sampled in the center of each plot; therefore, we believe migration of free-living ticks into the exclosure had little effect on our results.

The numbers of each tick life stage present on samples depend, in part, on the feeding success of the previous parasitic stage. We found no significant differences in average numbers of adult lone star ticks on deer excluded plots than on control plots, but we did find substantial differences on early samples of the overwintered population. Furthermore, nymphal lone star ticks exhibited greater host-finding success outside the exclosure, as indicated by a faster rate of decrease in numbers of nymphs collected on control plots. Therefore, we conclude that white-tailed deer were important hosts for nymphal lone star ticks. We found significantly fewer nymphs on plots inside the exclosure than outside the exclosure, and even larger differences early in the season. Therefore, we conclude that deer were important hosts also for larval lone star ticks.

Larval ticks are the progeny of female ticks that have successfully fed, mated, and oviposited. Lone star larvae were 98% fewer inside the exclosure than outside for all 3 study years. Since deer were the only abundant large host animals in the area (coyotes and feral dogs may have been present, but were uncommon), we conclude that deer were the major hosts for adult lone star ticks. We observed a significant decrease in larval lone star ticks collected with dry ice between 1979 and 1982. Since deer were the principal adult hosts, we suggest the decrease in larval ticks may have been caused by the reduction in the deer population which occurred during that time interval. While the accuracy of deer population estimates cannot be directly verified, we believe deer numbers decreased substantially in the vicinity of the exclosure.

Cooney & Burgdorfer (1974) reported that white-tailed and fallow deer were the preferred hosts of adult lone star ticks at LBL, while small mammals were the most important hosts of immature stages. Their collections of deer, however, occurred mainly during the hunting season in late fall. Our results show that deer were the principal hosts for adult lone star ticks at LBL, and both
deer and small mammals were important hosts for the immature stages. These results are supported by the findings of Bishopp & Trembley (1945), Clymer et al. (1970), and Patrick & Hair (1977). Authors have reported that host utilization of habitats plays an important role in lone star tick population densities (Semtner et al. 1971, Patrick & Hair 1978, Mount 1981). We attribute reinfestation of the enclosure by lone star tick adults and nymphs to movement of small host animals between enclosed and adjacent untreated areas. Although deer were important hosts for the immature stages, differences between enclosed and control plots indicate that the majority of immature lone star ticks fed on small mammals.

 Pretreatment numbers of American dog ticks are unknown; however, changes that occurred in American dog tick populations during the course of this study were different in the enclosed area than in the control area. In successive years following commencement of deer exclusion, populations of adult American dog ticks increased significantly in the enclosed field. We do not know why this occurred. Perhaps exclusion of deer from the field habitat resulted in an increase in desirable plant species, making the enclosed field more attractive to hosts of immature dog ticks (e.g., lagomorphs and rodents). Possibly, natural predators of the above hosts were hindered by the fence while trying to capture these prey species.

 In assessing the potential for deer exclusion as a method of controlling ticks, the size of the enclosed area and its surroundings are important considerations. The 2.43-ha enclosure in this study provided adequate control for larval lone star ticks but not for adults and nymphs. Small mammals responsible for reinfestation, such as raccoons, foxes, and skunks, can easily have home ranges covering several square kilometers. The distance of daily movements depends on a number of factors, including species, age, sex, population density, habitat, food abundance, and season. If adequate control of all life stages of the lone star tick is attainable through deer exclusion, the enclosure would have to be substantially larger than 2.43 ha, or have some physical characteristic that would inhibit the movement of small mammals between infested areas and the enclosure. In addition, the potential for an increase in American dog tick populations should be considered.

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