

Effect of Deer Reduction on Abundance of the Deer Tick (*Ixodes dammini*)

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To evaluate the role of deer in regulating the abundance of the deer tick (*Ixodes dammini*) we attempted to treat with acaricide, but eventually removed, about 70 percent of deer from Great Island, Cape Cod, Massachusetts. Deer were captured in box traps, a corral, an entanglement net, and with rifle-fired tranquilizer. Failure of these attempts, combined with ineffective acaricides, led us to deer destruction begun in fall 1982. Larval tick abundance on mice was monitored before and after deer removal. We concluded that deer removal, to the extent accomplished, did not markedly reduce the abundance of the tick.

Reduced abundance of deer may not result in reduced abundance of immature ticks if deer removal follows the period of adult tick feeding, or if intensity of infestation per deer increases, or if other mammals substitute as suitable hosts. Reduced tick abundance may be delayed if unattached immature ticks survive more than one year.

INTRODUCTION

Small rodents harbor numerous immature deer ticks (*Ixodes dammini*) [1-4] whereas white-tailed deer (*Odocoileus virginianus*) seem to be the main hosts for the adult stage of this tick in New England [2,3,5-7]. The importance of the white-footed mouse (*Peromyscus leucopus*) derives from its own abundance in that region and from its apparent attractiveness as a host. Nevertheless, the abundance of the tick may be independent of this particular host [8]. Other rodents (especially sciurids) serve as hosts to immatures, as do some insectivores, lagomorphs, carnivores, artiodactyles (especially deer), and even birds [3,4]. This notably broad host range of immature ticks contrasts with the restricted host range of adults. Deer are most heavily infested, although carnivores as well may harbor adult ticks [2,3]. Nevertheless, the typically greater density of deer and greater density of adult ticks per deer suggests that deer may be critically important hosts for the adult stage.

This apparent host specificity on the part of adult *I. dammini* may provide a point of vulnerability that could be exploited in efforts to reduce populations of the tick. Accordingly, we determined whether abundance of deer determines the density of the deer tick. In particular, we sought to reduce the availability of deer in a location in which *I. dammini* was abundant and to document an anticipated reduction in the abundance of this tick.

METHODS

Study Sites

Our study was undertaken on Great Island in West Yarmouth, Massachusetts, ($41^{\circ}37'N$, $70^{\circ}16'W$), a 240 ha. island connected to southern Cape Cod by a narrow causeway and bordered to the west, south, and east by Lewis Bay, Nantucket Sound, and the Atlantic Ocean (Fig. 1). The long, narrow causeway on to the island, which reduced ease of access by deer, made this an ideal site for this study. An oak-pine forest covers most of the island interior, with beach grass, poison ivy, and deciduous brush around the perimeter and causeway. Numerous small and medium-sized mammals and at least 30 resident white-tailed deer inhabited the island. Between 100 and 200 human summer residents occupied 27 houses interspersed around the island. Deer ticks and deer have been abundant for at least ten years and the incidence of Lyme disease has approached 6–8 cases per year.

Nantucket Island, Massachusetts, 40 km south of Great Island, served as a non-intervention area for comparison. Deer and deer ticks were also abundant there and Lyme disease and human babesiosis were well documented.

Measures of Tick Abundance

Relative density of larval and nymphal *I. dammini* was estimated by regularly trapping small mammals from which ticks were removed and later identified and counted. Small mammals were live-captured using oat- and cotton-baited Longworth traps placed in 7×7 grid patterns. Traps at each grid were placed 7.6 m apart, an interval which ensured that most mammals within the grid area encountered a trap during each trapping period. Trap locations were marked and held constant throughout the study. Five 49-trap grids (G,L,M,P,S) (Fig. 1) were each trapped about monthly from April through September during 1981, 1982, and 1983. Each trapping session lasted two days; traps were set in late afternoon and were checked during the morning for two days thereafter. Captured mammals were transported to a field laboratory where they were identified, weighed, sexed, ear-tagged (Fingerling Fish Tags; Salt Lake Stamp Co., Salt Lake City, UT), and promptly released at the point of capture. Ectoparasites were removed (using forceps) and stored in 70 percent ethanol for later identification. Mammals recap-

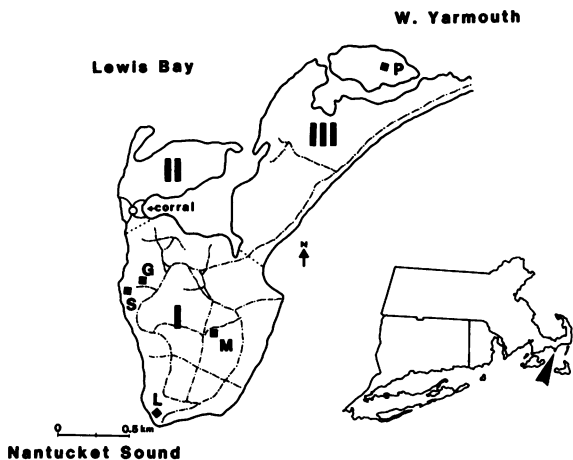


FIG. 1. Map showing Cape Cod, Massachusetts, and location of Great Island, plus detail of Great Island showing locations of mouse-trapping grids (G,L,M,P,S), island regions (I,II,III), roads, and corral.

tured on the second day of each trapping session were similarly released at the point of capture.

To reduce error in our estimates of tick abundance resulting from microhabitat differences, the five trapping grids were located at widespread locations which spanned the range of habitat types. For this reason, estimates were solely based on samples taken from the white-footed mouse, the most frequently trapped and most heavily infested small mammal.

The abundance of mice was estimated during the three years under study. Monthly samples from closely spaced traps arranged in a grid pattern permitted estimates of the number of mice from complete enumeration [9]. Relative mouse abundance was compared by calculating the minimum number alive [10].

Small mammal trapping on Nantucket Island was undertaken as described above except that traps were placed in lines every four to six weeks from May through September at two sites.

Deer Capture and Treatment

In an effort to reduce the success of adult ticks in attaching to deer, we attempted to capture and tranquilize these animals and externally apply acaricide or repellent during the adult questing season. Use of systemic treatment was impractical because of the inability to control dosage and the possibility of inadvertent human consumption. In fall 1982 we obtained permission to tranquilize deer in order to topically apply Amitraz (Tactic, Boots Co., Ltd) or Tetrachlorvinphos impregnated discs (Rabon Cattle Ear Tags, Diamond Shamrock Corp.) placed in both ears. Color-coded streamers were also attached to both ears to aid in later field identification. Our estimates of the number of deer were facilitated by individual identification and by counts during the capture effort.

Deer were captured using four methods: (i) baited box traps, (ii) an entrapment corral, (iii) entrapment nets, and (iv) rifle-fired tranquilizer.

i. Baited Box Traps Eight 3.7 m × 1.2 m × 1.2 m wooden box traps [11] with two trip-wire released doors were periodically operated during fall through spring 1981–82. Over about 225 trap-days, three deer were trapped of which two were tranquilized, tagged, and released (one deer, injured in confinement, was euthanized). All deer were captured in late winter when food was most scarce, even though trapping periodically occurred from early fall through spring.

ii. Entrapment Corral Modeled after the African "boma" used to herd and contain ungulates, an entrapment corral was constructed in fall 1981 at a narrow neck of the island (Fig. 1). Nylon netting (2.54 cm mesh, 3 m high) and opaque plastic sheeting were hung from posts encircling a .05 hectare forested area. Two spreading guide walls converged on each of two entrances. These "funnels" were designed to direct deer into the corral in advance of a coordinated drive team. Once inside, the entrance would be closed, and the deer immobilized with rifle-fired tranquilizer, then treated and released.

On 17 October and 7 November 1981 as many as 90 volunteers participated in four drives. The drivers walked slowly in line, each making noise and counting deer seen hiding or passing through the advancing line. Sections of the island were walked so that deer were progressively driven toward the corral.

Eight of 18 deer were entrapped on the first drive. All showed signs of extreme exhaustion (open-mouthed breathing, apparent hyperthermia); one yearling male was unable to stand. Frantic movement produced tears in the sheet and eventually the

netting. All deer except for the incapacitated animal escaped. This acidotic animal was treated and released.

For the next drive, the corral was reinforced with bailed hay stacked 1.5 m high and drivers walked more slowly. None of eight deer, however, entered the corral. One deer, showing signs of acidosis, was treated, tagged, and released as before (and was found dead a few months later).

iii. Entrapment Net A third deer capture technique utilized entrapment nets into which deer were driven. This technique has been successful in the capture of deer and elk in southwestern U.S. [Snyder W: personal communication]. Notched poles (2 cm × 2 cm × 3 m) leaning in opposing pairs supported hanging nets (20 cm sq mesh, 2.4 m high, 30 m long) placed in a series. A 210 m net line was thereby established near the old corral site on 30 October 1982. Eighteen volunteers walked, as in prior deer drives, from the tip of region II toward the net. Seven of nine deer were driven to the vicinity of the net but were not entangled. A capture team member drove into the net one deer which was bodily restrained, tranquilized, tagged, and released.

iv. Rifle-Fired Tranquilizer The fourth capture technique used a tranquilizer-loaded dart, fired from a rifle while spotlight-searching from a vehicle at night. A modified 22-caliber rifle (Palmer Chemical and Equipment Co., Douglasville, GA) was used to fire "Cap-chur" darts loaded with Etorphine hydrochloride (M.99, American Cyanamid), xylazine (Rompum, Haver Lockhart), or ketamine hydrochloride (Ketaset, Bristol Laboratories). Radio-telemetry transmitters were attached to some darts to aid in locating darted deer. We slowly searched by truck for deer standing within 40 m of the road, beginning at dusk and into the night. During approximately 80 search-hours in winter-spring 1982 we successfully darted, captured, and tagged nine deer (Table 1).

Deer Removal and Census

Because few deer were treated with acaricide and treatment occurred after the fall 1981 period of adult activity, we anticipated no impact on that year's adult feeding. The difficulty of deer capture and the questionable efficacy of acaricidal treatment led us to conclude that deer removal by killing constituted the only feasible method of reducing the availability of deer as hosts for ticks.

Accordingly, on 12 and 18 October of 1982, officials from the Massachusetts Division of Fisheries and Wildlife removed 13 deer from Region I, using high-powered rifles and spotlights. An additional five deer were removed in January and April 1983. To estimate the percentage of the deer herd removed and amount of host-availability days ticks were denied, we relied on four measures of deer abundance: nighttime spotlight counts, deer drives, daytime sightings, and counts of deer removed.

Nighttime spotlight counts were made at least monthly from a slowly moving truck, using a 300,000 candlepower spotlight. A standard route covering all island roads (Fig. 1) was driven at five mph, while observers slowly scanned the woods watching for eye-shine. Daytime sightings were made by R. Wilcox, Superintendent of Great Island, or by other employees who noted time, place, and, when possible, identity of all deer seen during the course of their work. Many of these animals could be individually recognized, either by their distinguishing colored ear tags, or by peculiarities of appearance and behavior. Deer drives, described above, were designed to survey inaccessible areas and to substantiate results from other methods.

TABLE 1
 Estimated Deer Abundance and Known Deer Removed in Region I
 of Great Island, Massachusetts, 1981-1983

Date	Deer Drive	Census Method		Deer Removed	Estimated Maximum Abundance
		Spotlight Census	Daytime Sighting		
Summer 81			18-20		(20)
17 Oct. 81	18				18
14 Feb. 82				-2*	16
Summer 82			(16-18)		18
12 Oct. 82				-6	
17 Oct. 82				-7	
20 Oct. 82		0	2		3
27 Oct. 82		0	3		5
19 Nov. 82		5	6-7		7
16 Dec. 82		3	4-6		8
10 Jan. 83		5	NA		8
11 Jan. 83				-3	
24 Feb. 83		0	4-5		6
14 Apr. 83		5	6-7	-2	5

* Accidental deaths

RESULTS

We estimated that 30-35 deer inhabited all of Great Island prior to deer removal, of which 16-18 were in Region I (Table 1). Following the October removal of 13 deer, a nighttime spotlight survey revealed no deer, and we estimated a maximum population of two to three. Thus, we calculate an initial deer reduction of at least 70 percent in Region I. Monthly surveys and daytime sightings indicated a gradual increase in deer during early winter; consequently on 10 January 1983, three additional deer were removed from Region I, thereby maintaining the estimated population at three to five. A similar increase was observed toward spring, and two more deer were removed on 14 April 1982.

Estimates of tick density were derived by counting ticks on mice. Mean larvae per mouse was similar in 1981 and 1982, but appeared to have increased at three of the five grids in 1983 (Fig. 2); however, fewer mice were present in that year than in previous years. Thus, this apparent increase in relative larval density converted to an overall decrease in total tick abundance. Indeed, total larvae per grid decreased from 1982 to 1983 at all grids except P, where little or no deer reduction had occurred (Fig. 3). Analysis of variance that modeled seasonal trend, trap-grid, and year interactions demonstrated that the number of larvae was not statistically different among the three years. We conclude that larval abundance may have decreased, but that such an effect was minimal.

Mean nymphs per mouse similarly appeared to be constant for all grids combined in 1981 and 1982 (Fig. 4). But nymphs declined in 1983, both in mean per host (Fig. 4) and in total abundance (Fig. 5).

Observations on tick density on Nantucket Island indicated that no changes had occurred during the study period (Table 2). Because the traps were set in lines rather than grids, comparable estimates of mouse abundance and total ticks could not be calculated.

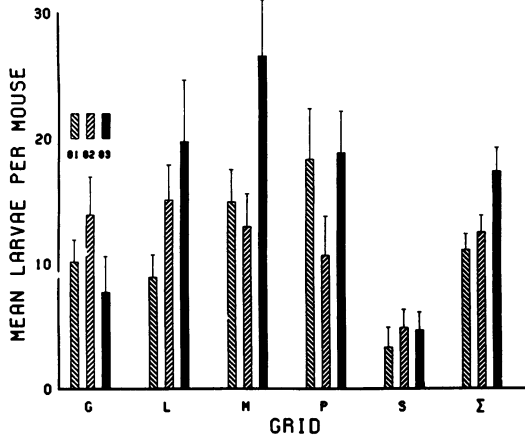


FIG. 2. Mean (± 1 SE) larvae per mouse during 1981, 1982, and 1983 by grid and for all grids combined.

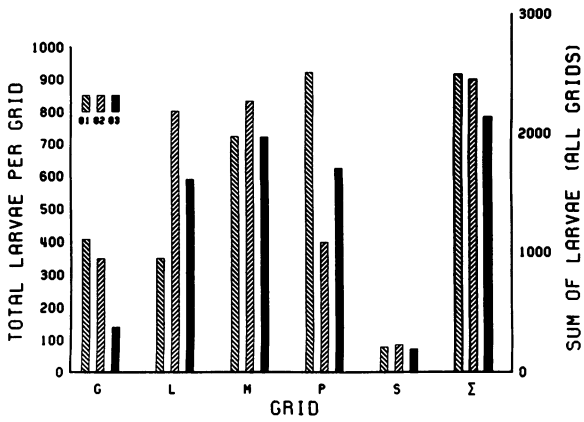


FIG. 3. Total number of larvae removed from mice in 1981, 1982, and 1983, by grid and for all grids combined.

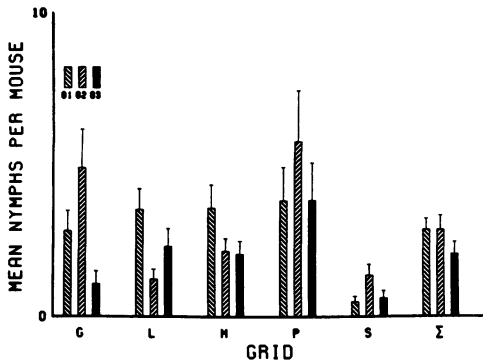


FIG. 4. Mean (± 1 SE) nymphs per mouse during 1981, 1982, and 1983 by grid and for all grids combined.

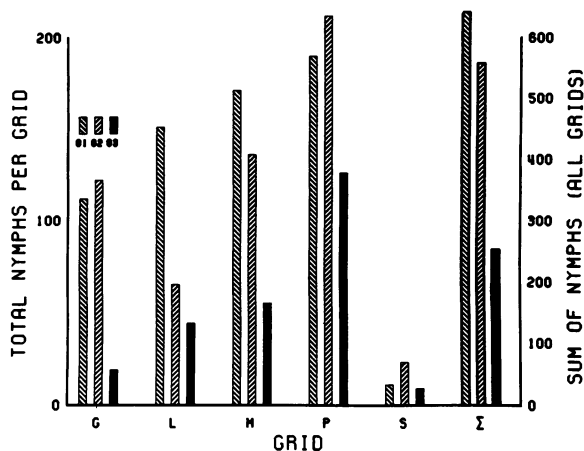


FIG. 5. Total number of nymphs removed from mice in 1981, 1982, and 1983, by grid and for all grids combined.

DISCUSSION

Effective reduction in the availability of deer hosts to *I. dammini* would be followed by reduced abundance of larval ticks in the event that deer serve as essential hosts for the adult stage. We believed that we had markedly reduced deer availability during the winter of 1982–1983 and had anticipated a consequent effect on larval abundance during 1983. No effect upon nymphal abundance was anticipated until the summer of 1984. Our results do not conform to these expectations. Although abundance of larvae seemed less in 1983 than in previous years, the difference did not approach the anticipated magnitude. Furthermore, the observed decline in nymphal abundance was not expected.

There may have been fewer total larval *I. dammini* attached to mice in 1983 than in 1982 or 1981 but the difference is too small to be significant. Two problems complicate analysis: an unexplained paucity of mice as well as fewer nymphs on mice in 1983 relative to previous years. Paucity of mice would result in increased relative density of ticks per mouse, as observed. In addition, each mouse in a reduced population might cover a larger range more thoroughly than before, thereby accumulating more ticks per mouse, and this is consistent with our observations. Thus, marginally reduced total abundance of larval *I. dammini* may merely represent an apparent effect due to changes in the number of mice. Paucity of nymphs further complicates analysis. We know of no environmental factors that can account for this reduction. Indeed, parallel observations on nearby Nantucket Island demonstrated larval as well as nymphal constancy throughout this period.

TABLE 2
Larval and Nymphal *I. dammini* on Mice Trapped
at Two Nantucket Island Sites During 1981–1983

Year	No. Mice	\bar{X} (\pm SE) Ticks per Mouse	
		Larvae	Nymphs
1981	88	4.94 \pm 0.97	1.44 \pm 0.29
1982	41	4.66 \pm 0.88	1.66 \pm 0.37
1983	33	4.88 \pm 0.80	1.24 \pm 0.40

Failure to accomplish the anticipated reduction in abundance of larval ticks following deer removal may be explained as follows: (a) intervention occurred relatively late in the adult season and too few deer were removed, (b) an increased relative density of ticks per deer compensated for the reduced number of deer, (c) other mammals were used as hosts by adult ticks, and (d) attached larvae include a cohort from previous years. We now consider each of these hypotheses.

Adult tick activity generally begins during September/October [1,3,5; personal observation] and deer removed in this study during October already had engorging adults. However, a substantial number of adults continue questing into December and are again active during early spring. While some adults undoubtedly fed prior to deer removal, we estimate that the intervention was in effect roughly 80 percent of the total tick questing-days of the 1982-83 adult season. We furthermore estimate that by reducing deer abundance to about 70 percent of previous levels during most of this period, we should have reduced the number of available-host days by roughly 50 percent. Corresponding reduction in larval abundance could have been recognized but was not observed.

It may be that deer range farther at low densities than at high densities. Thus, to a degree, reduced abundance of deer would result in increased tick attachment per deer. Of course, if deer density were reduced sufficiently, the tick-scanning capacity of each deer would be exceeded and adult ticks would fail to attach to hosts. If other mammals are important hosts for adult *I. dammini*, then our deer removal would have reduced the available-host days by less than estimated. The only animals likely to serve as major hosts for adult *I. dammini* on Great Island are foxes (no feral dogs are present). Foxes are typically less abundant than deer, though Great Island has an unusually large fox population (fall estimates average from 8-12). In this setting, foxes could represent a significant factor in adult tick feeding.

If non-attached larval *I. dammini* survive one or more years, then reduced deposition of eggs would not be manifest in reduced larval abundance until two or more years after deer removal.

Although our deer removal effort failed to demonstrate that abundance of deer limits density of *I. dammini*, indirect evidence for this relationship continues to be persuasive. That is, the tick is abundant solely where deer are abundant, and adult *I. dammini* generally most heavily infest deer. We shall continue to monitor tick populations in the study sites.

In our experimental study, we attempted to develop non-destructive methods for reducing availability of deer as hosts to *I. dammini*, but these efforts failed. Removal of deer remained our sole practical recourse, and this may be an effective method for protecting inhabitants of presently infested locations against Lyme disease. Of course, the efficacy of this measure has not conclusively been established.

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