Efficacy of a Permethrin-Based Acaricide To Reduce the Abundance of *Ixodes dammini* (Acari: Ixodidae)

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ABSTRACT Permethrin-impregnated cotton was distributed to reduce abundance of immature *Ixodes dammini* Spielman, Clifford, Piesman & Corwin feeding upon white-footed mice (*Peromyscus leucopus*) and questing on vegetation at a private resort site (The Crane Reservation of The Trustees of Reservations in Ipswich, Mass.) located in coastal New England. This test constituted the first independent evaluation of the efficacy of this commercial product (Damminix). Over a 3-yr period, 2,000 applicator tubes containing treated cotton were distributed over the 7.3-ha site in 5 regularly scheduled applications. Mice removed treated fiber from the tubes and transported it to their nests. Within 3 wk of the first application, virtually all mice in the treated site were rendered free of ectoparasites. After the first season of application, no nymphal host-seeking *I. dammini* could be found on vegetation. Visitor and employee complaints about deer tick bites or ticks found on skin and clothing had been attributed to the site before treatment, but not thereafter. We confirmed the efficacy of Damminix for reduction of the abundance of vector ticks and thereby contributed to the protection of humans against Lyme disease at this site.

KEY WORDS Arachnida, *Ixodes dammini*, Lyme disease, fiber-formulated acaricide

LYME DISEASE, a tick-borne spirochetosis of the white-footed mouse, *Peromyscus leucopus*, that is perpetuated as a zoonosis where white-tailed deer, *Odocoileus viginianus*, are abundant (Spielman et al. 1985), has recently affected the health of numerous residents of coastal New England. Annual incidence of Lyme disease among human residents of deer-infested sites may exceed 5% (Lastavica et al. 1989). However, protection of human populations has proved difficult (Spielman 1988). On an island where deer were eliminated, the vector population became markedly reduced within 2–3 yr, and human infections virtually disappeared (Wilson et al. 1985). Although effective, this public health measure generally seems distasteful and impractical, particularly in mainland situations where deer readily repopulate. Conventional applications of acaricide also appear impractical because of the difficulty in placing sprays or granules in the nests of the mouse reservoir host (Mather & Spielman 1986). A commercially available product called Damminix (Ecohealth, Boston, Mass.) features cotton balls impregnated with permethrin and placed in paper applicator tubes. Damminix was devised to circumvent the difficulty associated with deer reduction or with introduction of chemicals into the environment. At two experimental sites, Damminix rendered mice free of ectoparasites (Mather et al. 1987, 1988).

The Crane Reservation, a site used by ≈250,000 summer visitors in north-coastal Massachusetts, was affected by Lyme disease beginning around 1980. Four of ≈40 groundskeepers employed on the Reservation acquired infection during the first several years of the epizootic. About 35% of the people who live within 5 km of the Reservation and 66% of the residents bordering the reservation had contracted Lyme disease between 1980 and 1987 (Lastavica et al. 1989). The appearance of this focal zoonosis correlated with the development of an acute overpopulation of white-tailed deer (Moen 1984). Although the abundance of deer was reduced throughout the reservation by about four times from 1985 to 1989 (Deblinger 1989), additional measures designed to protect human health appeared essential.

To reduce the abundance of vector ticks, we applied Damminix to the portion of the Crane Reservation that is most intensely subject to human use. Abundance of vector ticks (nymphal *I. dammini*) attached to reservoir mice and questing on vegetation was estimated after this treatment.

Materials and Methods

The permethrin impregnated cotton balls in tubes were distributed on Castle Hill, a portion of the 567-ha Richard T. Crane, Jr., Memorial Reservation located in Ipswich, Mass. The Reservation is owned and managed by The Trustees of Reservations, a private, nonprofit conservation organization. Castle Hill itself is an 81-ha drumlin rising from the Atlantic Ocean. The mansion located on the apex of the hill is surrounded by formal grounds and lawns that have been used for a summer festival, concert series, and other functions such as weddings and receptions. The property is open to the public throughout the year. Pine and mixed deciduous woodlands and underbrush intersperse with the lawns on Castle Hill. The 7.3-ha apex of Castle Hill was designated as the treatment site. For comparison, nonintervention study sites were established ≈1 km to the northwest and 2 km to the southeast in equivalent habitats.

Damminix was purchased from the manufacturer (Ecohealth, Boston, Mass.) and distributed as specified on the package label at 10-m intervals throughout potential mouse habitat. During 1987, the 1st yr of the study, acaricide was distributed in the treatment site on 3 August. Two treatments were administered during 1988, the first on 20 May and the second on 13 August. Similarly spaced treatments were applied during 1989, one on 2 June and the other on 12 August. A total of 400 applicator tubes were distributed in the 7.3-ha site during each application. The label for the product instructs the user to place tubes in mouse habitat only. Lawns are generally not used by mice, so no mowed grass lawns were treated. Had the entire site been suitable for treatment, nearly 400 more applicator tubes might have been placed each year. Thus, 2,000 acaricide applicators were distributed in the treatment site in five applications spaced over three summer seasons.

To monitor changes in the abundance of vector ticks on reservoir hosts, white-footed mice were live-trapped periodically in Longworth Traps on permanently marked study plots. Each captured mouse was visually inspected for the presence of ticks, as previously described (Wilson et al. 1988). During each 3-d trapping session, traps were set on the 1st d and inspected during the early morning hours on each of 2 consecutive d. Each mouse was thoroughly examined and all parasites were removed to vials of ethanol by means of forceps. Mice were then marked with serially numbered metal ear tags and released at the point of original capture. Mice marked on the 1st d of a trapping session and recaptured on the second day were not reexamined for ticks. All ectoparasites were later identified by trained staff at the School of Public Health, Harvard University, Boston, Mass.

Traps were set in the intervention site on three grids, each comprised of 33 traps arrayed in three columns of 11 traps placed at 10-m intervals. The grids were placed at least 100 m from the margin of the treated site to avoid capture of mice that may have entered transiently from external nontreated sites. An additional grid was established about 1 km to the northwest and two additional grids were located south of the intervention site, where no acaricide had been distributed but in apparently similar habitat. Each nonintervention site grid contained 49 traps symmetrically arrayed in seven columns of seven traps placed at 10-m intervals. Intervention and nonintervention trap grids were of unequal sample size and spatially different in an attempt to place all traps in apparently similar habitats. We placed traps in shrub thickets and brush undergrowth in mixed deciduous and coniferous woodlands. Traps were not placed in open, grass lawns. Although all such habitat was treated with Damminix in the intervention site, less acreage existed to support mouse traps than in the nonintervention sites. Mice were trapped on all grids just before the first treatment in July 1987, 1 mo after this event and just after each subsequent spring and midsummer distribution of acaricide. The final distribution occurred in September 1989.

The abundance of host-seeking ticks was established periodically by dragging low-lying vegetation with segments of 1 m^2, light color, flannel-like cloth that were attached flaglike to a pole. The cloth was examined for ticks at frequent intervals. Flagging for questing ticks took much more time at nonintervention sites because tick abundance was much higher. Flagging material was checked every few minutes and numerous ticks were collected. At intervention sites, flagging material was searched every few minutes but was quickly reemployed because no ticks could be found. Harvard School of Public Health staff assisted in this sweeping operation. All ticks were preserved and later identified to species as described above.

Results

A sample of applicator tubes distributed in the treatment site were examined to determine whether acaricide-treated fiber had been removed by mice. Indeed, cotton gradually disappeared from virtually all applicators inspected during the course of the study. We attempted to discover and excavate the nests of mice in the treatment site to determine whether acaricide-treated mice had transported the fiber to their nests. Two such nests were discovered, and both were thoroughly lined with material apparently identical to the treated cotton distributed in the applicator tubes.

We evaluated the immediate effect of the acaricidal treatment by surveying mice for ectoparasites throughout the course of the study. Mice captured just before the first distribution of acaricide were mainly infested by larval *I. dammini*, the developmental stage of this tick most evident on hosts during early August (Table 1). Larval ticks were abundant in both sites, but their density on mice was greater in the site designated for acaricidal treatment than in the nonintervention sites. Initial evaluations were performed 24 and 54 d after treatment and at regular intervals for 2 yr thereafter. Subadult *I. dammini* remained abundant and at similar levels on each of three grids in the nonintervention sites throughout the study period. In contrast, only one subadult *I. dammini* was found on mice where acaricide had been distributed, and that specimen was found during the first examination of mice after treatment.

Table 1. Abundance of subadult *I. dammini* attached to mice (*P. leucopus*) on three trapping grids in nontreated sites and on three others located nearby where fiber-formulated permethrin had been distributed

Sample date	Nontreated sites				Treated 18-acre site			
	No. mice	% with ticks	Larvae/ mouse, $\bar{x}$	Nymphs/ mouse, $\bar{x}$	No. mice	% with ticks	Larvae/ mouse, $\bar{x}$	Nymphs/ mouse, $\bar{x}$
July 1987[a]	20	95	11.7	1.6	13	100	26.3	0.4
Aug 1987	32	91	10.6	0.7	14	1	0.1	0
Sept 1987	51	88	3.4	4.9	7	1	0	0.1
June 1988	6	100	9.0	6.3	11	0	0	0
Sept 1988	61	74	8.3	0.6	15	0	0	0
July 1989	46	93	7.9	0	24	0	0	0
Sept 1989	78	97	7.5	0.1	15	0	0	0

[a] Before acaricidal treatment.

In a more direct measure of the effect of the acaricidal application on human health, we compared the abundance of questing nymphal *I. dammini* in the treatment site to that in apparently similar adjacent nontreated sites. All samples were taken during June and July when vector-competent stages of this tick are abundant. In general, a tick could be swept from vegetation in nontreated sites in about 2 or 3 min (Table 2). In contrast, almost no questing ticks could be found after many hours of sweeping the treated area.

Discussion

Distribution of Damminix on the Castle Hill site effectively rendered all mice entirely free of *I. dammini*. In addition, the acaricide reduced the abundance of questing *I. dammini* on vegetation so that a person using the treated area would unlikely encounter a tick. Indeed, complaints from visitors and employees about tick-bites or ticks observed on skin or clothing, which were common in the study site before intervention, became rare after treatment.

Additional efforts have been conducted to reduce the risk of Lyme disease within the study site. The abundance of white-tailed deer has been reduced using a controlled, limited hunt, and the results of this study will be reported elsewhere. This deer reduction program should not confound the results of this study because deer hunting reduced the deer population equally over the entire study site, including both the acaricide-treated and comparison sites (Deblinger 1989).

Table 2. Abundance of questing nymphal *I. dammini* present on vegetation in adjacent nontreated areas and within the study site where fiber-formulated acaricide was distributed

Date	Nontreated sites		Treated site	
	Hours swept	Nymphs/ hour	Hours swept	Nymphs/ hour
12 June 1989	7.9	150	0	—
15 June 1989	5.7	13	1.3	0
16 June 1989	6.1	57	0	—
28 June 1989	1.8	60	0	—
1 July 1989	3.0	30	0	—
2 July 1989	3.6	122	1.5	0
3 July 1989	2.0	114	0	—
5 July 1989	1.3	342	0	—
6 July 1989	0.3	84	0	—
12 July 1989	0.3	246	0	—
20 July 1989	0.3	108	0	—
15 June 1990	1.0	3	1.0	0
20 July 1990	2.0	61	2.0	2

The efficacy of Damminix most likely depends upon the diversity and abundance of *I. dammini* hosts. At the Castle Hill study site, the primary and reservoir host for immature *I. dammini* is the white-footed mouse (Levine et al. 1985), which uses cotton as a nesting material. At sites where different species of small mammals are common *I. dammini* hosts, the efficacy of Damminix may depend on whether or not these host species line their nests with cotton.

Only one evaluation of the efficacy of acaricidal spray against Lyme disease has been published (Schulze et al. 1987). This effort to reduce the abundance of adult *I. dammini* reported a diminution of questing adults after the wintertime application of acaricidal emulsions on the bare branches of brush and trees. Although such a treatment temporarily protects deer from infestation by ticks in the sprayed site, the treatment would not necessarily result in significantly reduced future generations of immature *I. dammini*, and therefore, would not directly decrease the risk of Lyme disease transmission to humans.

The Castle Hill study constitutes the first independent evaluation of the efficacy of commercially formulated fiber-formulated acaricide in the reduction of immature *I. dammini* on mice. The only previously reported evaluations (Mather et al. 1987, 1988) were published by investigators who had obtained patent protection (Mather et al. 1985) for its commercial use. Fiber-formulated acaricide will continue to be used to protect public health at the Crane Reservation.

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