

Host Associations of *Ixodes scapularis* (Acari: Ixodidae) in Residential and Natural Settings in a Lyme Disease-Endemic Area in New Jersey

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ABSTRACT We live-trapped small mammals and flagged vegetation within wooded natural and residential landscapes to examine how any observed differences in small mammal species composition may influence *Ixodes scapularis* Say burdens and the abundance of host-seeking ticks. Two years of live trapping showed that Eastern chipmunks, *Tamias striatus*, were captured with significantly greater frequency in some residential areas than white-footed mice, *Peromyscus leucopus*, whereas the proportion of white-footed mouse captures was higher or similar to chipmunk captures in the undeveloped natural areas. Both mice and chipmunks seemed to adapt well to managed residential landscapes, with residential sites yielding similar or significantly greater numbers of captures compared with undeveloped sites. In areas where chipmunk captures outnumbered mice, larval tick burdens on mice were either higher or no different than in areas where few or no chipmunks were captured, in contrast to previous studies suggesting that alternate hosts should reduce larval burdens on mice. Chipmunks apparently play an important role in the Lyme disease transmission cycle in these residential settings.

KEY WORDS *Ixodes scapularis*, *Tamias striatus*, Lyme disease

ALTHOUGH *Ixodes scapularis* Say feeds on a variety of mammalian and avian hosts in the northeastern United States, it is widely accepted that the white-footed mouse, *Peromyscus leucopus* Raphinesque, is the most important maintenance host for subadult ticks and the principal natural reservoir of *Borrelia burgdorferi*, the etiologic agent for Lyme disease (Anderson et al. 1983, 1985; Bosler et al. 1983, 1984; Levine et al. 1985; Bosler and Schulze 1986; Donahue et al. 1987; Anderson 1988; Lane et al. 1991). In host association studies in natural forested habitats, *P. leucopus* was the most abundant species and outnumbered the next most frequently captured mammal by ratios of >2–4:1 (Carey et al. 1980, 1981; Main et al. 1982; Schulze et al. 1986; Schmidt et al. 1999). These studies demonstrated that *I. scapularis* larvae tend to parasitize mice more frequently and that nymphs were generally more abundant on larger hosts such as the Eastern chipmunk, *Tamias striatus*, and eastern gray squirrel, *Sciurus carolinensis*. Although several studies reported chipmunks to be competent reservoirs of *B. burgdorferi* (McLean et al. 1993; Slajchert et al. 1997; Ostfeld and Keesing 2000), their reservoir potential was considered negligible by virtue of lower host density, lower host in-

fectivity, and larval tick burdens compared with mice (Mather et al. 1989).

However, the apparent predominance of white-footed mice in the Lyme disease transmission cycle may not be universal. In a natural area in northwestern Illinois, for example, chipmunks were found to be as abundant as mice, exhibited markedly higher nymphal tick burdens, had higher infestation levels for larvae in some instances, and exhibited greater host potential compared with mice (Mannelli et al. 1993). Schmidt et al. (1999) suggested that such regional differences may reflect host preferences of ticks and differences in host encounter rates as a measure of habitat preferences of potential hosts. In addition to geographic variability, Fish and Dowler (1989) suggested that the importance of mice as the principal reservoir host may diminish in suburban residential landscapes because such areas often artificially increase the food supply for alternative hosts and such disturbed habitats are generally less favorable to mice by comparison. In contrast, Ostfeld and Keesing (2000) and LoGuidice et al. (2003) argue that forest fragmentation adversely affects vertebrate biodiversity and community composition and that as a habitat and dietary generalist, mice thrive in degraded forested habitats of the kind that tend to characterize many residential communities in Lyme disease endemic areas.

Although it seems that mice can be supplanted in their dominant role in the Lyme disease transmission cycle by other reservoir-competent hosts such as chipmunks (Mannelli et al. 1993), the ecological circumstances under which this occurs have not been

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adequately investigated, because virtually every published study on tick–host associations has been conducted in natural areas. In this study, we attempted to compare the roles of *P. leucopus* and *T. striatus* as hosts for subadult *I. scapularis* between wooded natural and residential landscapes and to examine how any observed differences in species composition may influence tick burdens and abundance of host-seeking ticks.

Materials and Methods

Study Areas. The study was conducted in Millstone Township, Monmouth County, and Mendham Township, Morris County, which are located in central and northern New Jersey, respectively. The Millstone residential site is composed of a 48 single-family development located on ≈ 66 ha of mixed hardwood forest dominated by chestnut oak, *Quercus prinus* L.; red oak, *Quercus rubra* L.; and white oak, *Quercus alba* L., with associated species including red maple, *Acer rubrum* L.; yellow poplar, *Liriodendron tulipifera* L.; black gum, *Nyssa sylvatica* Marsh.; and American beech, *Fagus grandifolia* Ehrh. The understory and shrub layer consists of saplings and seedlings of the aforementioned tree species, highbush blueberry, *Vaccinium corymbosum* L.; lowbush blueberry, *Vaccinium angustifolium* Ait.; huckleberries, *Gaylussacia* spp.; sweet pepperbush, *Clethra alnifolia* L.; and greenbriar, *Smilax glauca* Walt. Contiguous forested habitats of similar species composition in nearby Assunpink Wildlife Management Area (WMA) and the adjacent Borough of Roosevelt served as the Millstone undeveloped areas. Undeveloped areas were characterized by intact canopy forest with edge habitats restricted to unimproved roads providing access to trap sites.

The Mendham residential site consists of 89 single-family residences located on ≈ 175 ha of mixed hardwood forest consisting of mature second-growth forest typical of the northern phase mixed oak forest described from the Highlands physiographic province of north central New Jersey (Collins and Anderson 1994). The canopy is dominated by red oak; chestnut oak; yellow poplar; sassafras, *Sassafras albidum* (Nutt.) Nees; and sugar maple, *Acer saccharum* Marsh., with an understory of eastern red cedar, *Juniperus virginiana* L., and hickory, *Carya* spp. The understory consisted of the dominant canopy species, in addition to black cherry, *Prunus serotina* Ehrh.

There was a sparse to very dense shrub and herbaceous layer consisting primarily of scattered barberry, *Berberis thunbergii* D.C.; brambles, *Rubus* spp.; Japanese honeysuckle, *Lonicera japonica* Thunberg; sumac, *Rhus* spp.; bittersweet, *Celastrus scandens* L.; and snakeroot, *Eupatorium* spp. Shrub layer and herb layer density varied widely within and among study properties. In some developed areas, there was minimal shrub layer with an open, denuded understory that lacked hard and soft mast-producing species. Interviews with residents suggested that these conditions are the result of extensive and long-term overbrowsing by white-tailed deer (*Odocoileus virginianus* Zimmerman). Much of the forested area was charac-

terized by considerable amounts of fallen woody material (branches and trunks). An area of ≈ 60 ha of similar forested habitats adjacent to the residential site was used as the Mendham undeveloped site. As at Millstone, the undeveloped area was a contiguous, closed canopy stand with edge habitat confined to roadways providing access.

In contrast to the uniform forested habitats found at the undeveloped sites, the residential sites were characterized by an array of successional and actively managed habitats. Few properties had large expanses of maintained lawn or landscaped areas (typically <20% of lot area). The majority of these largely wooded lots were adjacent to protected wetlands, greenbelts, and other undisturbed forest so that cleared areas surrounding the footprint of the house and paved driveways created patches of impervious cover and successional habitats among wooded corridors and forest patches of various sizes (0.1–0.4 ha). Woodpiles, brush piles, and plant debris disposal areas were common at both residential sites. Thus, the residential areas studied here are contiguous, albeit not natural, wooded settings characterized by a continuous disturbance regime generated by homeowners, including maintenance of successional habitats through mowing and clearing, creating refuges and harborage, and supplying food sources (planting hard and soft mast, establishing bird feeders, disposing of waste materials).

Small Mammal Trapping and Tick Burdens. Small mammals were collected using Sherman nonfolding box traps (7.6 by 8.9 by 30.5 cm) (H.B. Sherman, Tallahassee, FL) baited with rolled oats and cotton balls. At both study sites, traps were operated for 1 d monthly between May and August 2002 and 2003. The May and June trapping events were intended to correspond to the peak activity period of *I. scapularis* nymphs, whereas the July and August dates correspond to the peak larval activity period in New Jersey (Schulze et al. 1986). During 2002, 150 traps each were set at each Millstone and Mendham residential and undeveloped site, totaling 600 trap nights for each monthly trapping event. In 2003, the number of trap-nights was increased to 200 for each residential site and natural area, for a total of 800 trap nights for each session. At each site, transects were established in transitional wooded habitats likely to be used by foraging small mammals. At the residential sites, transects were placed in wooded habitats at distances of 10–20 m from the lawn–forest interface, whereas at the undeveloped sites, transects were typically situated in wooded ecotones in proximity to oldfield habitats or unimproved access roads. Traps were set along transects at each site by mid-afternoon and retrieved the next morning. Captured mammals were anesthetized with isoflurane, examined for ticks, and released at the point of capture. All ticks located within a 2-min inspection period were removed using fine-pointed forceps and placed in individual vials containing 70% ethanol for subsequent identification.

Tick Collections. Abundance of host-seeking ticks was monitored at 10, 100-m² plots established within

Table 1. Comparison of small mammal captures in residential and undeveloped sites in Millstone Township, Monmouth County, and Mendham Township, Morris County, New Jersey

Location	Species	No. of Captures			
		Date			
		May–June 2002	July–August 2002	May–June 2003	July–August 2003
Millstone Township					
Residential	<i>P. leucopus</i>	26	12	10	30
	<i>T. striatus</i>	44	26	66	68
	<i>B. breviceauda</i>	4	2	4	3
	<i>D. marsupialis</i>	0	0	1	0
	<i>G. volans</i>	1	0	1	0
	<i>M. pennsylvanicus</i>	0	0	0	0
	Total	75	40	82	101
Undeveloped	<i>P. leucopus</i>	31	25	47	45
	<i>T. striatus</i>	12	0	5	4
	<i>B. breviceauda</i>	1	0	0	0
	<i>G. volans</i>	0	0	0	0
	<i>M. pennsylvanicus</i>	0	1	0	0
	Total	44	26	52	49
Mendham Township					
Residential	<i>P. leucopus</i>	26	23	32	11
	<i>T. striatus</i>	18	12	25	25
	<i>B. breviceauda</i>	0	0	1	0
	<i>G. volans</i>	0	0	0	0
	<i>M. pennsylvanicus</i>	0	0	0	0
	Total	44	35	58	36
Undeveloped	<i>P. leucopus</i>	41	18	14	13
	<i>T. striatus</i>	19	21	22	21
	<i>B. breviceauda</i>	0	0	2	0
	<i>G. volans</i>	0	0	0	0
	<i>M. pennsylvanicus</i>	0	0	0	0
	Total	60	39	38	34

each residential and undeveloped site. Plots were placed in wooded habitats in the general vicinity where trapping was conducted. However, because *I. scapularis* subadults tend to quest within the litter layer, plots were situated in areas with sparse shrub layer vegetation to facilitate more frequent contact between the drag and forest floor. The relative abundance of *I. scapularis* at each plot was estimated by use of the flagging/dragging method (Ginsberg and Ewing 1989, Schulze et al. 1997). Sampling was performed to coincide with trapping events and conducted between 0800 and 1200 hours when vegetation and leaf litter were dry and wind was below 10 km/h (Schulze et al. 2001a, Schulze and Jordan 2003). To avoid sampling biases, dragging was performed by the same individuals throughout the study. During sampling, drags were worked across each 10 by 10-m plot and inspected at 20-m intervals (Schulze and Jordan 2001). All ticks removed from the drags were transferred to individual vials containing 70% ethanol for later identification.

Statistical Analyses. Differences in questing *I. scapularis* populations between study sites and numbers of subadult ticks infesting captured small mammals were compared using analysis of variance (ANOVA) or nonparametric equivalent (Sokal and Rohlf 1981). Comparisons of the relative numbers of *P. leucopus* and *T. striatus* in small mammal captures between study sites and of tick burdens between mammal species were made using χ^2 and Mann–Whitney *U* tests, respectively. All statistical tests were performed using Statistica analysis packages (StatSoft, Inc. 1995).

Results

Small Mammal Trapping. In total, 813 small mammals were captured during all trapping events (Table 1). The Millstone residential site yielded 298 mammals composed of five species. Chipmunks ($n = 204$) were the dominant small mammal in six of eight trapping events, representing 68.5% of the total captures, and were roughly three times more abundant in traps than white-footed mice ($n = 78$), which made up 26.2% of all captures. At the Millstone undeveloped site, 171 mammals were captured, representing four species. Mice ($n = 148$) were the dominant species in all eight trapping sessions, including 86.5% of total captures, and were more than seven-fold more abundant in traps than chipmunks ($n = 21$). Overall, nearly twice as many small mammals were captured at the residential site compared with the undeveloped site. Species other than mice and chipmunks comprised 5.3 and 1.2% of all captures at the Millstone residential and undeveloped sites, respectively. Chipmunks comprised a significantly larger proportion of captures in the residential setting than in the natural area ($\chi^2 = 149.35$, $df = 1$, $P < 0.01$).

At the residential site in Mendham, 174 small mammals in total were captured, representing three species. Mice ($n = 92$) were collected only slightly more frequently than chipmunks ($n = 80$), comprising 53.8% of captures and outnumbering chipmunk captures in five of eight trapping sessions. The Mendham undeveloped area yielded 171 small mammals representing three species. Mouse captures ($n = 86$) out-

Table 2. Summary of *I. scapularis* burdens and infestation rates on captured small mammals at residential and undeveloped sites in Millstone Township, Monmouth County and Mendham Township, Morris County, New Jersey

Location	Species	Mean tick burden \pm SE (% infested)			
		2002		2003	
		Nymphs	Larvae	Nymphs	Larvae
Millstone Township					
Residential	<i>P. leucopus</i>	2.6 \pm 0.5 (62)	15.4 \pm 3.9 (100)	0.4 \pm 0.2 (30)	3.6 \pm 0.8 (77)
	<i>T. striatus</i>	3.2 \pm 0.7 (70)	7.6 \pm 1.4 (54)	2.0 \pm 0.3 (83)	2.3 \pm 0.3 (69)
Undeveloped	<i>P. leucopus</i>	3.2 \pm 0.4 (74)	5.1 \pm 1.3 (80)	1.3 \pm 0.2 (60)	3.3 \pm 0.5 (82)
	<i>T. striatus</i>	8.2 \pm 1.1 (92)		3.2 \pm 0.2 (100)	2.5 \pm 1.3 (75)
Mendham Township					
Residential	<i>P. leucopus</i>	1.4 \pm 0.3 (31)	4.7 \pm 0.5 (91)	0.6 \pm 0.2 (38)	1.5 \pm 0.5 (64)
	<i>T. striatus</i>	3.1 \pm 0.8 (78)	9.0 \pm 0.9 (100)	2.4 \pm 0.3 (88)	2.4 \pm 0.3 (84)
Undeveloped	<i>P. leucopus</i>	1.7 \pm 0.2 (80)	3.7 \pm 0.5 (83)	0.8 \pm 0.3 (50)	1.9 \pm 0.5 (85)
	<i>T. striatus</i>	5.3 \pm 0.6 (100)	7.3 \pm 0.4 (100)	2.8 \pm 0.3 (91)	3.3 \pm 0.4 (95)

numbered chipmunk captures in three of eight trapping events and accounted for 50.3% of all captures. Species other than mice and chipmunks comprised 0.6 and 1.2% of all captures at Mendham residential and undeveloped sites, respectively. There was no significant difference in the proportion of chipmunk captures relative to mouse captures in the residential compared with the undeveloped area ($\chi^2 = 0.14$, $df = 1$, $P = 0.68$).

Tick Burdens. Mean nymphal and larval tick burdens and infestation rates for each small mammal species are summarized in Table 2. Because so few larvae and nymphs were found on small mammals during the peak nymphal (May and June) and larval (July and August) activity periods, respectively, these data are omitted from the analysis. At Millstone, nymphal tick burdens varied significantly between years ($F = 23.74$; $df = 1, 233$; $P < 0.01$), sites ($F = 14.49$; $df = 1, 233$; $P < 0.01$), and mammal species ($F = 21.02$; $df = 1, 233$; $P < 0.01$). Nymphal burdens were higher on chipmunks than on mice and higher at the undeveloped site than at the residential site. Larval burdens at Millstone varied between years ($F = 33.37$; $df = 1, 203$; $P < 0.01$), sites ($F = 9.05$; $df = 1, 203$; $P < 0.01$), and mammal species ($F = 4.34$; $df = 1, 203$; $P = 0.04$). Larval burdens were greater in 2002 and greater on mice than on chipmunks at both sites.

At Mendham, nymphal burdens were significantly higher in 2002 ($F = 17.72$; $df = 1, 224$; $P < 0.01$), at the undeveloped site ($F = 13.92$; $df = 1, 224$; $P < 0.01$) and were significantly higher on chipmunks in both years and at both sites ($F = 85.54$; $df = 1, 224$; $P < 0.01$). Larval burdens varied significantly between years ($F = 107.06$; $df = 1, 136$; $P < 0.01$) and were higher on chipmunks than on mice ($F = 45.55$; $df = 1, 136$; $P < 0.01$), but did not differ between sites ($F = 0.79$; $df = 1, 136$; $P = 0.37$). Overall, nymphal burdens averaged 3 times higher on chipmunks than on mice, whereas larval burdens averaged 1.7 times higher on chipmunks than on mice.

At Millstone (where chipmunk were captured with greater frequency at the residential site and mice were captured more frequently at the undeveloped site), larval burdens on mice in 2002 were significantly greater at the residential site than at the undeveloped site [Mann-Whitney $U_{(12, 25)} = 48.0$; $P = 0.04$]. In

2003, larval burdens on mice at the residential site did not differ significantly from those at the undeveloped site [$U_{(30, 45)} = 649.5$; $P = 0.78$]. In 2002, the ratio of mice to chipmunks at the residential site was 12:26, whereas in 2003 it was 30:68. At the undeveloped site there were no chipmunks captured in 2002 and the ratio in 2003 was 4:45. Thus, in areas where chipmunk captures outnumbered those of mice, larval tick burdens on mice were either higher or no different from areas where few or no chipmunks were captured.

With few exceptions and irrespective of site, $\geq 50\%$ of mice and chipmunks captured during each trapping event were infested with subadult *I. scapularis* (range 30–100%). When all mice and chipmunks were considered ($n = 792$), the overall infestation rate was 76%. The infestation rate for all mice ($n = 404$) and chipmunks ($n = 388$) was 71 and 81%, respectively. Mice ($n = 226$) and chipmunks ($n = 225$) captured at the Millstone sites and mice captured at the Mendham sites had similar infestation rates of 73, 73, and 68%, respectively, whereas 91% of chipmunks captured at Mendham were infested. When captures from both residential areas were combined, 70% of mice and chipmunks were infested compared with 83% of mice and chipmunks captured at undeveloped sites. At the Millstone sites, the larval infestation rates were uniformly higher on mice and the nymphal infestation rates were higher on chipmunks, whereas at Mendham both nymphal and larval infestation rates were higher on chipmunks.

Tick Collections. The mean number of host-seeking *I. scapularis* obtained from dragging surveys at both Millstone and Mendham are summarized in Table 3. Again, because larvae and nymphs were rarely encountered during the nymphal and larval activity periods, respectively, data were excluded from analysis. At Millstone, nymphal abundance did not differ significantly between the residential site plots compared with those at the undeveloped site in 2002, although the numbers of nymphs per plot was higher in the residential site plots in 2003. Larval abundance was significantly greater at the Fox Hill residential area plots in 2002. At Mendham, the abundance of host-seeking *I. scapularis* nymphs and larvae was greater at the undeveloped area plots than at the residential site in 2002, but not in 2003. Overall, the abundance of

Table 3. Summary of host-seeking *I. scapularis* collected from residential and undeveloped sites in Millstone Township, Monmouth County and Mendham Township, Morris County, New Jersey

Location	Mean nymphs and larvae/100-m ² plot			
	2002		2003	
	Nymphs	Larvae	Nymphs	Larvae
Millstone Township				
Residential	7.8 ± 0.9a	104.9 ± 26.2a	5.2 ± 0.5a	76.1 ± 22.8a
Undeveloped	5.9 ± 0.7a	69.2 ± 28.7b	2.3 ± 0.5b	55.3 ± 20.3a,b
Mendham Township				
Residential	1.7 ± 0.4b	8.8 ± 1.3c	1.1 ± 0.3c	12.4 ± 1.1b
Undeveloped	2.4 ± 0.3c	28.5 ± 3.9d	1.5 ± 0.4c	19.9 ± 1.6a,b
ANOVA results ^a	F = 19.87 P < 0.01	F = 4.79 P < 0.01	F = 17.96 P < 0.01	F = 3.84 P = 0.01

^a ANOVA comparing residential and undeveloped sites between study areas. Values in the same column followed by the same letter are not significantly different.

host-seeking subadult *I. scapularis* was substantially lower at Mendham compared with Millstone. Numbers of questing ticks were not significantly related to either tick burdens or the number of small mammals captured.

Discussion

Two years of live trapping showed that Eastern chipmunks were captured with greater frequency than white-footed mice in the residential area at Millstone than at the undeveloped site and that the reverse was true at the undeveloped site. There was no significant difference in the relative proportion of chipmunks to mice captured at the Mendham sites. These results seem to be contrary to previously published studies in natural forested habitats which have suggested that *P. leucopus* was the most abundant species in small mammal communities (Carey et al. 1980, 1981; Main et al. 1982; Schulze et al. 1986; Schmidt et al. 1999) and studies describing increased numbers of mice (considered a habitat generalist) and decreased numbers of chipmunks (ostensibly a forest habitat specialist) in disturbed or fragmented forest situations (Nupp and Swihart 1998, Rosenblatt et al. 1999).

However, previous work was done in natural or "postagricultural" landscapes (Schmidt et al. 1999), where ecotones between habitats are abrupt and field-forest edges mark clear boundaries between habitats (Wear and Greis 2002). In contrast, at the Millstone and Mendham residential sites, few properties had extensive areas of maintained lawn. Partially wooded lots abutted greenbelts, protected wetland corridors, and other undisturbed canopy forest. Thus, the wooded residential landscape studied here is characterized by a mosaic of different seral stages (Tews et al. 2004) and is substantially different from a post-agricultural landscape containing isolated forested patches surrounded by cultivated and/or fallow fields. Small remnant patches of forest surrounded by cleared or early successional areas constitute unfavorable habitat for many species (see reviews in Pickett and White 1985). However, in the residential setting studied here, the entire array of seral stages may provide habitats for the dominant small mammals in the

community as they move through the landscape. Both mice and chipmunks were abundant in this managed landscape, and chipmunks seemed to be much more ecologically labile than previously reported.

Previous studies have indicated that *I. scapularis* larvae tended to parasitize mice more frequently than sympatric chipmunks. However, we found that in areas where chipmunks comprised a large proportion of the small mammal captures, larval tick burdens on mice were either higher or no different from areas where few or no chipmunks were captured. This also contrasts with previous work (Schmidt et al. 1999) that suggested that a high density of chipmunks reduced larval burdens on mice, indicating a dilution effect of chipmunks on mice. Schmidt et al. (1999) argued that disturbed/fragmented forest areas should support greater numbers of white-footed mice than other less reservoir competent hosts and consequently larger numbers of *I. scapularis* larvae should become infected with *B. burgdorferi*, resulting in greater potential human risk of exposure to Lyme disease. Our data suggest that chipmunks account for a greater proportion of the small mammal population in residential (disturbed/fragmented) areas than previously recognized and may feed more larvae than mice in some cases (Mannelli et al. 1993), whereas not reducing larval burdens on mice in others.

Additional study is needed to assess the applicability of the dilution effect model, developed in post-agricultural and natural forested areas where isolated habitat patches occur, to residential landscapes. However, chipmunks seem to be playing a substantial role in the disease cycle in our study areas. If chipmunks are at least a moderately competent reservoir host for *B. burgdorferi* relative to mice (Slajchert et al. 1997, Schmidt and Ostfeld 2001), then relative dominance of one or the other species may have similar effects on human risk. However, understanding how the structure of mammal communities in residential settings affects human disease risk also should include the potential role of larger mammals such as gray squirrels, which are abundant in our study areas and seem to be increasing in abundance in recent years (unpublished data). Tree squirrels in Europe seem to be reservoir competent for *B. burgdorferi* sensu lato, and squirrels

are known to feed large numbers of nymphs and larvae (Gern and Humair 2002, Eisen et al. 2004). LoGuidice et al. (2003) found that squirrels had relatively low reservoir competence (compared with mice and chipmunks) and may have the highest potential for reducing infection prevalence in *I. scapularis*. If squirrels harbor large numbers of ticks and they are increasing in residential settings as a result of habitat fragmentation (Fisher and Merriam 2000), we may see an increase or decrease in Lyme disease risk, depending on their relative reservoir competency. Further research is needed to understand the role of small mammal community structure in residential Lyme disease cycles.

Numbers of questing subadults were variable between natural and residential areas at both sites and in both years. No significant relationship was detected between numbers of host-seeking ticks and numbers of small mammals. Millstone sites yielded greater numbers of both nymphs and larvae than more northern Mendham sites. We have previously reported greater numbers of ticks in Inner Coastal Plain versus Piedmont areas in New Jersey (Schulze et al. 1998) that do not seem to be explained solely by differences in habitat. Where *I. scapularis* populations are established, tick abundance is correlated with the abundance of white-tailed deer (Piesman 2002). However, Schulze et al. (2001b) demonstrated that significant levels of deer activity, even where deer numbers were artificially elevated at baiting stations, was no guarantee of larger numbers of questing ticks. Regardless, proximity of residential and undeveloped sites at the two study areas makes it unlikely that any difference in deer density influenced the observed differences in tick abundance. Stafford et al. (2003) showed that fluctuations in tick numbers, responding to local weather conditions and small mammal host availability, may not correspond directly to deer density and suggested that the suite of extrinsic factors regulating tick populations remains poorly understood.

Capture rates at the several sites studied here suggest that chipmunks may play an important role in the Lyme disease transmission cycle in these residential areas. Further study is required to determine to what extent the posited dilution effect (sensu Schmidt and Ostfeld 2001) operates in the managed habitats characterizing these areas. Van Buskirk and Ostfeld (1995) suggested that maintaining mammalian diversity, by increasing the numbers of less reservoir competent hosts for larval *I. scapularis*, would increase this dilution effect and may effectively reduce human risk of acquiring Lyme disease. However, Lyme disease is substantially a peridomestic illness (Cromley et al. 1998), and it is not clear what recommendations regarding the maintenance of species and/or habitat diversity can be successfully adopted in residential settings. Homeowners in established communities and developers of new housing are unlikely to initiate habitat management schemes on a scale necessary to effect such a result.

However, we suggest that long-recommended means of habitat modification (Schulze et al. 1993,

Stafford and Kitron 2002), such as managing vegetation, removing rock walls, woodpiles and brush piles, reducing leaf litter in areas around homes, to discourage tick hosts, coupled with host-targeted technologies that attack ticks feeding on both mice and chipmunks (Dolan et al. 2004), offer effective solutions to the problem and should be further studied. As our understanding of the ecology of tick-borne zoonoses increases, we may come to better elucidate the practical management role of host diversity models in disease intervention. However, public health agencies require tools that can be readily implemented to combat disease. Adoption of relatively simple property management guidelines (Stafford 2004) and judicious application of habitat and host-targeted acaricides seem to be the most effective means of reducing tick encounters in residential settings.

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