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ABSTRACT Nymphal Ixodes scapularis Say deer ticks were collected at 22 parks or other natural areas on Long Island, New York, to examine the relationship between tick populations and geographic position, size of area, presence of white-tailed deer, Odorocoileus virginianus (Zimmerman), and numbers of human Lyme disease cases in adjacent communities. Nymphal ticks were 93% less abundant when deer were absent and were also less common in smaller natural areas. Geographic position on Long Island was not important. Tick numbers were significantly correlated with human Lyme disease incidence in adjacent townships. A second survey of larval ticks from five areas where deer were absent and six where deer were present found larvae present at four of the five sites without deer, but at only 2% of the levels found where deer were present. These results suggest that populations of I. scapularis can occur and reproduce in the absence of white-tailed deer, so that eradication of all deer would greatly reduce, but not eliminate, all risk of Lyme disease.

KEY WORDS Ixodes scapularis, landscape ecology, Lyme borreliosis
Fig. 1. Study sites sampled for *I. scapularis* on Long Island, New York. Numbers refer to study sites: Suffolk County: (1) Montauk County Park, East Hampton Town (455 ha), (2) Hither Woods County Park, Montauk, East Hampton Town (314 ha), (3) Gardiner’s Island, East Hampton Town (1,376 ha), (4) Grace Estate Preserve, East Hampton Town (34 ha), (5) Northwest Harbor County Park, East Hampton Town (136 ha), (6) Mashomack Preserve, Shelter Island (825 ha), (7) Goldsmith Inlet County Park, Southold Town (13 ha), (8) Hubbard County Park, Southport, Southampton Town (655 ha), (9) Quogue Wildlife Refuge, Southampton Town (81 ha), (10) Cranberry Bog County Park, Riverhead Town (85 ha), (11) Peconic River County Park, Manorville, Riverhead Town (813 ha), (12) South Haven County Park, Brookhaven Town (535 ha), (13) Cathedral Pines County Park, Middle Island, Brookhaven Town (130 ha), (14) Cordwood County Park, Miller’s Place, Brookhaven Town (27 ha), (15) Connetquot State Park, Bohemia, Islip Town (1,405 ha), (16) Heckscher State Park, East Islip, Islip Town (870 ha), (17) Caleb Smith State Park Preserve, Smithtown (237 ha), (18) Sunken Meadow State Park, Fort Salonga, Smithtown (512 ha), (19) Gardiner’s Point County Park, West Bay Shore, Islip Town (93 ha), (20) West Hills County Park, West Hills, Huntington Town (345 ha), (21) Caumsett State Park, Lloyd Neck, Huntington Town (601 ha). Nassau County: (22) Bethpage State Park, Old Bethpage, Oyster Bay Town (597 ha).

trends in reported human cases of Lyme disease, and (4) the size of natural areas affects tick numbers.

Materials and Methods

Study Sites. We chose study sites presenting a range of sizes and locations throughout eastern and central Long Island, New York. We obtained the areas of each park or natural area from the park administrations or local planning boards and ranked each area by size and by east-west location. We sampled 22 natural areas (Fig. 1).

We sampled only in deciduous or mixed woodlands with closed or nearly closed canopies or at the edges of such woodlands, habitats reported elsewhere to have the greatest proportion of ticks (Maupin et al. 1991). At each site, we concentrated our sampling as much as possible on shady leaf litter on the forest floor.

As an index of Lyme disease cases for each park, we used the 1990 incidence of Lyme disease cases reported by the Suffolk County Department of Health Services for each township within the county (L. Benincasa, personal communication).

Deer Distribution. We determined the presence or absence of deer at each park through direct observation of footprints, droppings, or direct sightings or through discussions with park officials familiar with each site.

White-tailed deer elsewhere often have large home ranges (Marchinton & Hirth 1984) and may undertake lengthy dispersals (Nelson & Mech 1992); however, movement on Long Island may be restricted by highways and housing developments, and some natural areas have been fenced to contain their deer.

If there is substantial movement of deer between natural areas, this tends to reduce regional variability in tick populations and to remove the independence of sites, leading to pseudocorrelation. We expected closer sites to show less difference in tick populations than those farther away, because of deer migration. To test this, we
compared the similarity in population size with distance between pairs of adjacent sample sites.

**Nymphal Survey.** Over a 15-d period (15–30 June 1992), during peak nymphal numbers in the northeastern United States (Piesman & Spielman 1979), we sampled nymphal *I. scapularis* with 30-s flaggings of 1-m² funnel (Ginsberg & Ewing 1989) on single-day visits by three to six people to each site. A 30-s flagging covered ≈7–10 m linear distance of the forest floor, depending on terrain and underbrush. Estimates of areal cover were not appropriate because the area of flag on the ground varies considerably, being least in dense underbrush and greatest on open forest floor.

Flagging of nymphs took place during 1000–1500 h. Adult *I. scapularis*, *Amblyomma americanum* (L.), and *Dermacentor variabilis* (Say) were present at different sites in small numbers and were excluded from analysis. Identification of nymphal and larval *I. scapularis* collected from areas beside Shelter Island was confirmed under stereoscopic microscope. The few individuals that proved to be *Ixodes dentatus* (Marx) or *Haemaphysalis leporispalustris* (Packard) were subtracted from the data (1.2% of 975 nymphs examined and 1.0% of 103 larvae examined).

**Larval Survey.** To determine if reproduction of *I. scapularis* had occurred at parks without deer, we revisited six sites without deer on 13 and 24 August 1992, during the larval peak in the northeastern United States (Wilson & Spielman 1985), sampling larval *I. scapularis* with 0.5-m² flags, using the same sampling methods as for nymphs except at Caumsett State Park, where we sampled larvae beginning at 0830 h. We compared these data with counts made between 11 and 25 August from five areas on Shelter Island, where deer were present and *I. scapularis* nymphs had been found previously.

**Analysis of Data.** For analysis, we took the mean of each individual’s flagging efforts for each site, then averaged them between individuals at each site. We then used the nonparametric Spearman Rank Correlation ($r_s$) (Siegel 1956) to compare these site population means against size of the park, east-west position on Long Island, and incidence of human Lyme disease cases. To test for possible lack of independence of tick population samples between sites because of deer movement, we compared the difference between tick populations and the distance between sites for pairs of adjacent sample sites, using a Spearman Rank Correlation. We also used a Spearman Rank Correlation to test whether sampling by the four principal tick collectors recorded similar trends in tick populations between natural areas. We used Mann-Whitney $U$ tests to compare tick numbers in the presence or absence of deer (Siegel 1956).

**Results**

**Deer Distribution.** Within the individual natural areas sampled, presence of deer was determined from direct sightings by members of the research group at Mashomack, Heckscher, Connetquot, Goldsmith Inlet, and Gardiner’s Island locations; presence of deer footprints or droppings at Montauk, Hither Woods, Northwest Harbor, Grace, Hubbard, Quogue, and Peconic River; as well as reports from park officials familiar with or resident at the Cathedral Pines, South Haven, and Cranberry sites. Absence of deer is difficult to prove, so we relied both on our lack of sightings during fieldwork and on interviews with park staff or residents familiar with each site (Caumsett, West Hills, Bethpage, Gardiner’s Point, Caleb Smith, Sunken Meadow, Cordwood). The two parks at the edge of the known deer range, Cordwood and Gardiner’s Point county parks, were visited repeatedly by a member of the research team, and no deer or their sign were encountered (D.C.D., personal observation).

The mean direct distance between pairs of sampling points where deer were present was 11.25 km (SD = 6.39; $n = 14$). The relationship between distance between sampling points and difference in tick populations was not significant ($r = 0.213$, $n = 14$, $P > 0.05$). The lack of correlation suggests that any movement of deer between sites had little effect on tick numbers and that little pseudocorrelation occurred.

**Nymphal Survey.** For nymphal tick sampling, we conducted 1,720 30-s flaggings at the 22 sites (Table 1) and collected 1,403 nymphal *I. scapularis*. Using data from 13 sites where the four main collectors of data (93% of 1,720 flaggings) sampled together, we found that the mean ticks per flag were significantly correlated between all four collectors ($r = 0.527–0.827$, $P < 0.05$ for six pairwise correlations).

Seventeen of the sites were sampled within one 5-d period; all 22 were sampled within 15 d. The frequency of occurrence of ticks per 30-s flagging was 33.0% for all sites, 44.5% for areas with deer, and 8.4% for areas without deer. The frequencies were significantly different (Mann-Whitney $U$ test, $n_1 = 7$, $n_2 = 15$; $U = 6$; $P < 0.001$). The frequency of occurrence per sample was significantly correlated with mean tick numbers ($r = 0.594$, $n = 22$, $P < 0.001$).

Numbers of nymphal *I. scapularis* ranged from 0.02 per 30 s at Gardiner’s Point County Park to 5.70 per 30 s at Connetquot State Park (Table 1), with a mean of means of 0.784 per 30-s sample (SEM = 0.27, $n = 22$). Natural areas without deer had only 7% of the nymphal tick populations within areas with deer. The seven parks without deer had a mean over all samples of 0.070 ticks per 30-s flag (SEM = ± 0.017); the 15 natural areas with deer had a mean over all samples
of 1,113 ticks per 30-s flag (SEM = ± 0.369). The means were significantly different (Mann-Whitney U test, n1 = 7, n2 = 15; U = 6; P < 0.001).

For parks with deer, there was a significant correlation between size of the natural area and the number of nymphae ticks (r = 0.71, n = 15, P < 0.01), a pattern reported at a much smaller scale for house lots in Westchester County (Maupin et al. 1991). The same trend existed for parks without deer (r = 0.75, n = 7, P < 0.05).

Geographic position on Long Island also did not seem to be important in determining tick numbers, when areas with deer were ranked west to east and compared with nymphae per 30-s flag for each area (r = 0.11, n = 15, P > 0.05).

Larval Survey. We surveyed six of the seven sites without deer (Cordwood was omitted for logistic reasons) in August (Table 2). We collected 420 samples and collected 118 larval I. scapularis. Larvae were collected in five of the six areas, but they had only 1.8% of the tick populations of areas with deer. The average of the six mean larval numbers was 0.30 larvae per 30-s flagging, and 13% of flaggings encountered at least one larva. In contrast, on Shelter Island, where deer were present, the average of means for 490 samples at five locations was 16.58 larvae per 30-s flagging, and the frequency was 97.4%. Both means and frequency were significantly different (Mann-Whitney U test, n1 = 7, n2 = 6; U = 0; P = 0.002).

Human Cases. The 1990 data on human Lyme disease cases reported by each township were the latest available (L. Benincasa, Suffolk County Department of Health Services, personal communication). The incidences of human cases reported for townships in Suffolk County were as follows: East Hampton, 343 per 100,000; Southold, 192 per 100,000; Shelter Island, 2,739 per 100,000; Southampton, 211 per 100,000; Riverhead, 151 per 100,000; Brookhaven, 60 per 100,000; Islip, 41 per 100,000; Smithtown, 37 per 100,000; Babylon, 14 per 100,000; and Huntington, 28 per 100,000.

The ranks of natural areas (excluding Bethpage State Park, which straddles the Suffolk and Nassau county line) based on numbers of nymphae ticks were significantly correlated with the numbers of human Lyme disease cases reported in 1990 in the surrounding townships (r = 0.45, corrected for ties, n = 21; P < 0.05).

Discussion

Our sampling was extensive, not intensive, and certainly does not reflect the full variability of tick populations within sites. Nevertheless, wide-scale, short-term sampling offers an exciting way to address specific questions about the landscape ecology of Lyme borreliosis at the mesoscale of 10–100 km and to assess whether it is possible to extrapolate from results at a particular site to the ecology of the disease at larger scales.

Table 1. Relative abundance of nymphae I. scapularis at different natural areas on Long Island, New York

<table>
<thead>
<tr>
<th>Site*</th>
<th>Mean ± SEM</th>
<th>Frequency</th>
<th>n</th>
<th>Date in June</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Montauk</td>
<td>0.83 ± 0.44</td>
<td>38</td>
<td>60</td>
<td>15</td>
</tr>
<tr>
<td>2. Heber Woods</td>
<td>0.50 ± 0.06</td>
<td>45</td>
<td>60</td>
<td>15</td>
</tr>
<tr>
<td>3. Gardiner's Island</td>
<td>2.22 ± 0.80</td>
<td>74</td>
<td>80</td>
<td>30</td>
</tr>
<tr>
<td>4. Grace Preserve</td>
<td>0.40 ± 0.08</td>
<td>32</td>
<td>60</td>
<td>15</td>
</tr>
<tr>
<td>5. Northwest Harbor</td>
<td>0.42 ± 0.16</td>
<td>35</td>
<td>60</td>
<td>15</td>
</tr>
<tr>
<td>6. Mashomack</td>
<td>0.94 ± 0.12</td>
<td>60</td>
<td>120</td>
<td>23</td>
</tr>
<tr>
<td>7. Goldsmith</td>
<td>0.04 ± 0.03</td>
<td>4</td>
<td>80</td>
<td>19</td>
</tr>
<tr>
<td>8. Hubbard</td>
<td>0.69 ± 0.16</td>
<td>36</td>
<td>80</td>
<td>17</td>
</tr>
<tr>
<td>9. Quogue</td>
<td>0.89 ± 0.19</td>
<td>51</td>
<td>80</td>
<td>26</td>
</tr>
<tr>
<td>10. Cranberry</td>
<td>0.24 ± 0.11</td>
<td>19</td>
<td>80</td>
<td>17</td>
</tr>
<tr>
<td>11. Peconic River</td>
<td>0.35 ± 0.08</td>
<td>28</td>
<td>80</td>
<td>17</td>
</tr>
<tr>
<td>12. South Haven</td>
<td>0.83 ± 0.18</td>
<td>50</td>
<td>80</td>
<td>17</td>
</tr>
<tr>
<td>13. Cathedral Pines</td>
<td>0.34 ± 0.13</td>
<td>20</td>
<td>80</td>
<td>17</td>
</tr>
<tr>
<td>14. Cordwood</td>
<td>0.04 ± 0.3</td>
<td>2</td>
<td>80</td>
<td>19</td>
</tr>
<tr>
<td>15. Connetquot</td>
<td>3.70 ± 0.35</td>
<td>95</td>
<td>80</td>
<td>15</td>
</tr>
<tr>
<td>16. Heckscher</td>
<td>2.31 ± 0.38</td>
<td>81</td>
<td>80</td>
<td>18</td>
</tr>
<tr>
<td>17. Caleb Smith</td>
<td>0.07 ± 0.05</td>
<td>7</td>
<td>80</td>
<td>36</td>
</tr>
<tr>
<td>18. Sunken Meadow</td>
<td>0.13 ± 0.05</td>
<td>19</td>
<td>80</td>
<td>26</td>
</tr>
<tr>
<td>19. Gardiner's Point</td>
<td>0.05 ± 0.04</td>
<td>1</td>
<td>80</td>
<td>18</td>
</tr>
<tr>
<td>20. Caumsett</td>
<td>0.14 ± 0.05</td>
<td>14</td>
<td>80</td>
<td>16</td>
</tr>
<tr>
<td>21. West Hills</td>
<td>0.11 ± 0.07</td>
<td>10</td>
<td>80</td>
<td>16</td>
</tr>
<tr>
<td>22. Bethpage</td>
<td>0.05 ± 0.04</td>
<td>6</td>
<td>80</td>
<td>16</td>
</tr>
<tr>
<td>Grand mean</td>
<td>0.78 ± 0.27</td>
<td>33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Numbers refer to locations on Fig. 1.
* Mean and standard error per 30-s flagging.
* Frequency of occurrence per flag.
* 1,720 total samples, number of samples taken per site.
* Deer are present.
* Deer are absent.

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The occurrence of larval ticks in August at five of six sites without deer clearly disproves this second hypothesis, although the numbers were again far fewer (98% reduction) than where deer were present.

Medium-sized mammals such as raccoons, Procyon lotor (L.), Virginia opossum, Didelphis virginiensis (Kerr), red foxes, Vulpes vulpes (L.), and feral and domestic dogs, although not important hosts for adult I. scapularis when deer are present (Wilson et al. 1990b), may allow sufficient reproduction of the ticks even in the absence of deer. Alternatively, horses and other large domestic animals could serve as hosts when they are present (Cohen et al. 1988). Caumsett State, Bethpage State, and West Hills County parks were the only parks where deer were absent and horses were present. These sites ranked first, third, and fifth for nymphal abundance ($n = 7$) and first to third for larval abundance ($n = 6$), but the sample size was too small to draw further conclusions.

Although $I$. scapularis may be able to reproduce where deer are absent, it remains to be seen whether such reproduction alone is sufficient to sustain tick populations (Fish & Dowler 1989). Immigration of larvae and nymphs transported by birds may assist in maintaining populations. Comparing the ratio of tick abundances in areas where deer are absent and present, the reduction was 93% for nymphs and 98% for larvae. The difference in percentage reduction between the nymphal and larval stages may be caused by avian introduction of larvae. If so, the effect of such immigration seems small, on the order of 10% or less.

In view of the greater incidence of human Lyme borreliosis cases in eastern Long Island and the significant relation of such cases with tick numbers in natural areas, it is interesting that there was no support for the hypothesis that tick numbers decrease from east to west in the natural areas where deer are present. Instead, heaviest infestations occurred in the largest natural areas (Connetquot, Heckscher, Mashomack, Gardiner's Island, and Montauk County Park), regardless of position, supporting the hypothesis that there was no support for the hypothesis that tick numbers decrease from east to west in the natural areas where deer are present.
that size of the reserve, not location, determines tick numbers when deer are present. It is not clear why larger areas should have more ticks, unless density of deer, as opposed to population size, increases with area size, allowing questing adult ticks a greater probability of encountering a host. Increasing density might result if larger areas tended to contain a greater variety of habitats needed to sustain deer populations throughout the year.

These results suggest that eradication of deer would greatly reduce but not eliminate populations of *I. scapularis*. Given the political controversy and economic costs of deer eradication, the benefits probably would not outweigh the costs. Nevertheless, our results strongly suggest that where deer are not present, they should not be allowed to become established, to avoid a major increase in any existing populations of *I. scapularis* and a much greater risk of human cases of Lyme borreliosis. Where deer are present, efforts to reduce adult tick parasitism of deer should be considered as a potential control mechanism.

Finally, our results and those from Monhegan Island, where Norway rats, *Rattus norvegicus* (Pallas), replace white-footed mice as reservoir hosts (Smith et al. 1992), suggest that *I. scapularis* in the northeastern United States could be present where both mice and deer are absent, such as inner-city parks. Although populations of *I. scapularis* and the associated risk of Lyme borreliosis in such areas are likely to be far lower than where the traditional hosts are present, the very heavy human use of urban parks increases the possibility of cases of Lyme borreliosis.

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