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Author(s): Howard J. Kilpatrick, Andrew M. Labonte, and Kirby C. Stafford, III
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The Relationship Between Deer Density, Tick Abundance, and Human Cases of Lyme Disease in a Residential Community

HOWARD J. KILPATRICK,[1,2] ANDREW M. LABONTE,[1] AND KIRBY C. STAFFORD, III[3]

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ABSTRACT White-tailed deer (*Odocoileus virginianus* Zimmerman), serve as the primary host for the adult blacklegged tick (*Ixodes scapularis* Say), the vector for Lyme disease, human babesiosis, and human granulocytic anaplasmosis. Our objective was to evaluate the degree of association between deer density, tick abundance, and human cases of Lyme disease in one Connecticut community over a 13-yr period. We surveyed 90–98% of all permanent residents in the community six times from 1995 to 2008 to document resident's exposure to tick-related disease and frequency and abundance of deer observations. After hunts were initiated, number and frequency of deer observations in the community were greatly reduced as were resident-reported cases of Lyme disease. Number of resident-reported cases of Lyme disease per 100 households was strongly correlated to deer density in the community. Reducing deer density to 5.1 deer per square kilometer resulted in a 76% reduction in tick abundance, 70% reduction in the entomological risk index, and 80% reduction in resident-reported cases of Lyme disease in the community from before to after a hunt was initiated.

KEY WORDS *B. burgdorferi*, hunting, *Ixodes scapularis*, Lyme disease, *Odocoileus virginianus*

White-tailed deer (*Odocoileus virginianus* Zimmerman), serve as the primary host for the adult blacklegged tick (*Ixodes scapularis* Say), the vector for Lyme disease, human babesiosis, and human granulocytic anaplasmosis (ehrlichiosis; Spielman et al. 1985, Spielman 1988, Bakken et al. 1994). Numerous researchers have correlated tick abundance with deer abundance (Rand et al. 2003, Stafford et al. 2003, Wilson et al. 1990). A positive correlation was found between density of deer pellet groups and adult tick densities in Maine (Rand et al. 2003) and between deer densities and tick abundance in Connecticut and New York (Wilson et al. 1990, Stafford et al. 2003). Anderson et al. (1987) evaluated the presence of *I. scapularis* (then *Ixodes dammini* Spielman, Clifford, Piesman & Corwin) and the Lyme disease agent, *Borrelia burgdorferi*, on six coastal islands in Rhode Island and found the blacklegged tick and *B. burgdorferi* only on islands inhabited by deer. The association between deer activity, deer and tick abundance, and the transmission of Lyme disease has been recognized, but not well quantified (Rand et al. 2003).

Several studies have documented the impact of reduced deer numbers on blacklegged tick activity. Tick numbers declined with the reduction of deer at the Bluff Point Coastal Preserve in Groton, CT, and a forested tract in Bridgeport, CT (Stafford et al. 2003). Near elimination of deer on Great Island and Crane Beach in Massachusetts resulted in reduction of ticks in years following the deer reduction (Wilson et al. 1988, Deblinger et al. 1993). Similarly, elimination of deer on Monhegan Island in Maine led to a decline in tick abundance and infection rates (Rand et al. 2004). Telford (1993) reported that before the deer reduction on Great Island, a peninsula on Cape Cod Massachusetts, 20% of residents contracted a tick-related disease. After deer were reduced from between 39–65 deer per square kilometer to 1–3 deer per square kilometer, no new cases of tick-related disease were reported over the next 8 yr (Steere et al. 1986, Wilson et al. 1988, Telford 1993).

It is unclear how low deer densities need to be reduced to affect tick abundance sufficiently to reduce the incidence of human Lyme disease. Telford (1993) suggested that deer populations need to be reduced to <3 deer per square kilometer to reduce the zoonotic overflow of Lyme disease to humans. Computer simulations suggested that deer density maintained at 7.5 deer per square kilometer would result in a 40% reduction in infected nymphs, while near elimination was needed to lower the density of infected nymphs >90% (Mount et al. 1997). However, other models suggest that adult hosts (white-tailed deer) had no influence on controlling tick population densities under most circumstances (VanBuskirk and Ostfeld 1995, Ostfeld et al. 2006).

Only Steere et al. (1986) and Telford (2002) reported a reduction in tick-related disease in humans after a reduction in the deer population; however, no details were provided on the sampling methods. Kilpatrick and Walter (1997) and Kilpatrick and LaBonte

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[1] Department of Energy and Environmental Protection, Wildlife Division, 391 Route 32, North Franklin, CT 06254.

[2] Corresponding author, e-mail: Howard.Kilpatrick@ct.gov.

[3] The Connecticut Agricultural Experiment Station, 123 Huntington St., Box 1106, New Haven, CT 06504.

(2003) reported reduced community concerns about deer and Lyme disease the year following a controlled deer hunt. However, no studies have simultaneously evaluated the relationship between deer density, tick abundance, and incidence of Lyme disease in humans before and after initiating a deer reduction program in a residential community. Our objective was to evaluate the degree of association between deer density, tick abundance, and human cases of Lyme disease in one Connecticut community over a 13-yr period.

Study Area

The study area was the Mumford Cove (MC; 80.9-ha) community in Groton, CT. The number of occupied residences in MC year-round varied from 98 to 119 during the study. House lots were ≤0.61 ha each. MC was situated on a 1.9-km^2 coastal peninsula bordered by Long Island Sound to the east and west. North of the peninsula was an 80-ha undeveloped state park closed to hunting and separated from MC by a 1.83-m-high chain-link fence. South of MC was the 105.9-ha residential community of Groton Long Point. Adjacent to residential development in MC were three tracts of open space (24.5, 22.7, and 21.4 ha each; Fig. 1).

A local ordinance prohibiting hunting in MC allowed the local deer population to grow unimpeded. As a result of this population growth, resident concerns associated with overabundant deer populations increased in the 1990s (Kilpatrick et al. 1996). From 1995–2000, 63 female deer were radio collared and ear tagged (83–100% of annual estimated spring female population over a 6-yr period) and 13 males were ear tagged only in the community to examine deer movements (Kilpatrick and Spohr 2000a, b). In July 2000, the community voted to eliminate the no-hunting ordinance, and implement a deer hunt in their community (Kilpatrick et al. 2002).

A 6-d shotgun-archery hunt in November 2000 on two of three tracts of open space reduced the targeted deer herds by 92% (Kilpatrick et al. 2002). The following year the third tract of open space was opened to hunting. A 3-d shotgun-archery hunt during November 2001 targeted deer herds on all three tracts of open space and reduced the existing deer population by 82%. Over the next 6 yr (2002–2007), a team of two to three hunters were assigned to each tract of open space during the archery deer season (15 September–31 December) to maintain the deer population at low densities. Under existing state hunting regulations, archery hunters were allowed to harvest unlimited numbers of antlerless deer. In 2003, the archery season was extended to 31 January and hunters were allowed to hunt over bait.

Methods

Population Estimate. We conducted aerial deer surveys 9 of 13 yr between 1995 and 2007 (1995, 1996, 1999, and 2002–2007) from a helicopter when complete snow cover was available during January or February. All radio-collared deer were confirmed to be in the study area at the time of the surveys. Before the hunt, a correction factor was developed to account for deer not observed during aerial surveys. The correction factor was based on the number of known radio-collared deer in the population compared with the number of radio-collared deer observed during aerial surveys (Kilpatrick et al. 2001). This correction factor of 2.2 was applied to all deer counts to estimate deer densities.

Homeowner Surveys. We surveyed all permanent residents in MC six times from 1995 to 2008. We asked residents if a physician had diagnosed them or any member of their household with Lyme disease and during which years. On all surveys residents were asked to indicate during what years they contracted Lyme Disease which covered a 12-yr period (1996–2007). On four of six surveys, we also asked residents how often they observed deer and how many they observed (1995, 1999, 2001, and 2005). Deer observations were categorized into group sizes consisting of 0, 1–3, 4–6, 7–9, and 10+. For our analysis, we focused on sizes of ≥4 because it likely represented an extended family group consisting of more than a doe and her immediate offspring.

The first survey was conducted by going door-to-door in August 1995, before initiation of any deer management program. For the remaining five surveys, we conducted a mail-back survey of all permanent residents in MC following methodologies suggested by Dillman (1978). The second survey was conducted in August 1999 before the controlled hunt was initiated. Based on the timing of the surveys, some questions referenced interactions from previous years to incorporate complete years of data. The third (July 2001) and fourth surveys (September 2002) were conducted after the first (2000) and second (2001) controlled hunts were completed. The fifth and sixth surveys were conducted in July 2005 and 2008 after bow hunting was established in the community as an annual management program.

The study protocol and surveys were reviewed and approved by the Connecticut Wildlife Division. We conducted surveys in accordance to federal guidelines by excluding minors, ensuring results were not identifiable to individuals, and ensuring that the surveys involved no risks to individuals.

Tick Collection. The abundance of host-seeking nymphal blacklegged ticks in MC was monitored by dragging a 1-m^2 fleece cloth along transects at lawn edges and at wooded plots ranging from 25 to 137 m in length. Sampling occurred May through September from 2001 to 2007. Average nymphal tick abundance per 100 m^2 was based on June and July peak season samples. All nymphs of *I. scapularis* were returned to the laboratory for testing for *B. burgdorferi* by indirect florescent antibody staining of mid-gut tissues as previously described (Magnarelli et.al. 1987). An entomological risk index (ERI) or average number of infected ticks per unit area was calculated as the product of the average number of nymphs per area and pro-

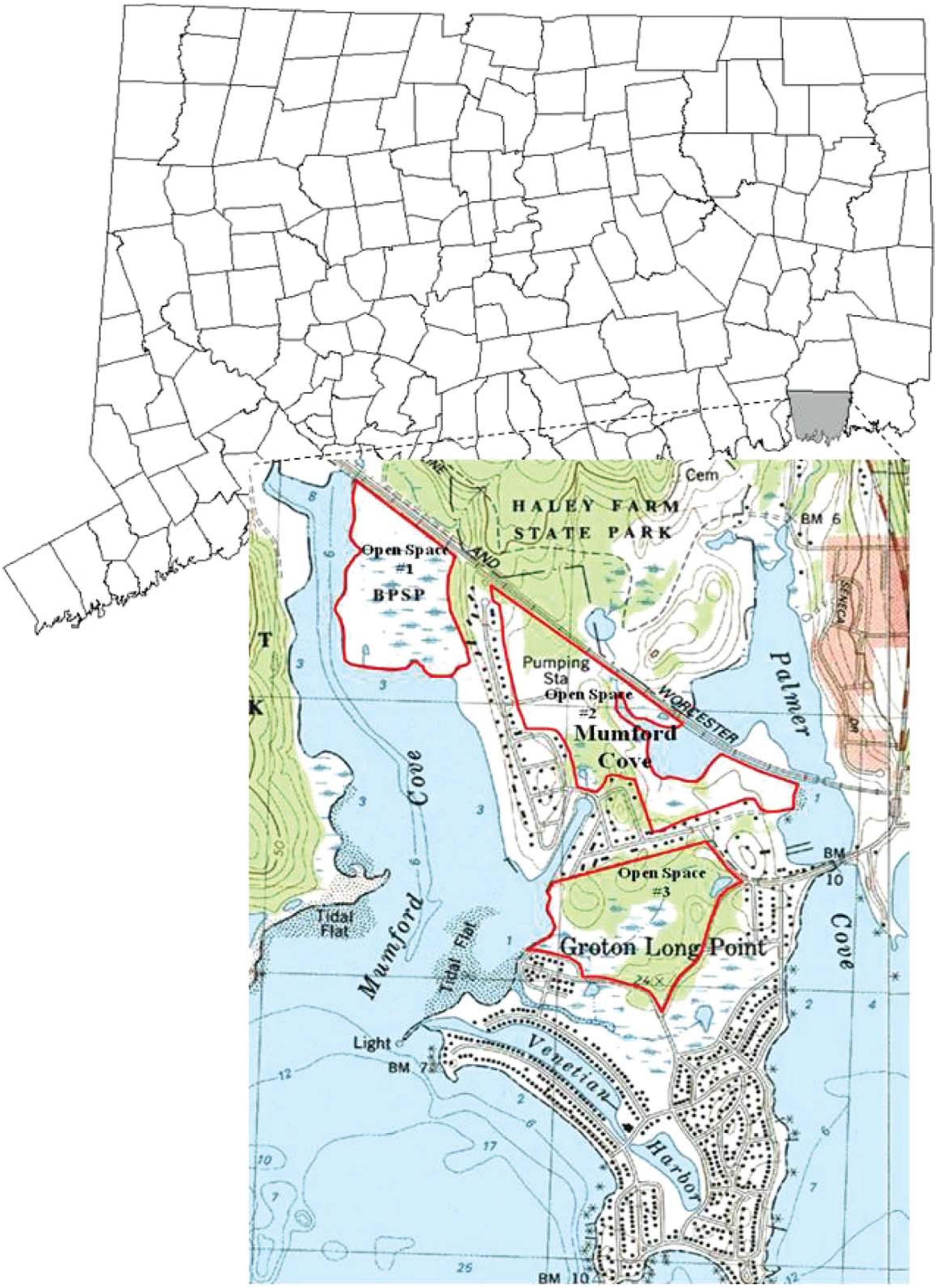

Fig. 1. MC and adjacent Groton Long Point community in Groton, CT, with tracts of open space. Red lines delineated three tracts of land open to hunting.

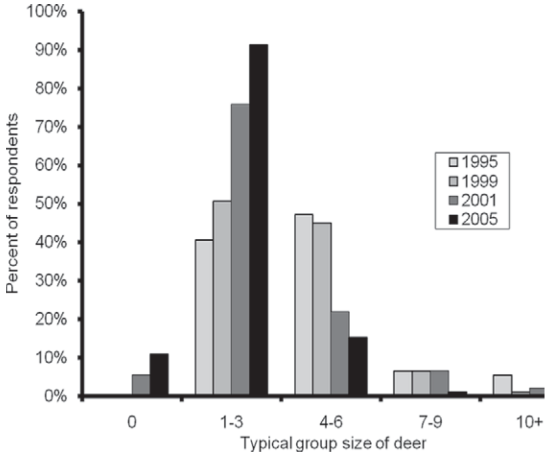

Fig. 2. Typical group size of deer observed by residents in the MC Community, Groton, CT, 1995–2005.

portion of ticks infected with *B. burgdorferi* (Stafford et al. 1998).

We used least square linear regression analysis (Systat Software, Inc., San Jose, CA) to test for correlations between cases of Lyme disease and deer densities, daily deer sightings, and nymphal tick abundance ($P < 0.05$). We tested for differences in number and frequency of deer observations in the community using Spearman's rank correlation ($P < 0.05$). We tested for differences in mean number of cases of Lyme disease in the community before and after the hunt using the Mann–Whitney U ($P < 0.05$). Nymphal tick abundance between years was compared using Kruskal–Wallis one-way analysis of variance followed by a pair-wise multiple comparison (Dunn's method $P < 0.05$; Systat Software, Inc., San Jose, CA).

Results

Survey response rates among all six surveys ranged from 90 to 98%. The size of the deer groups sighted by residents in the community differed among years ($\rho_{9.0} = 0.254$; $P < 0.001$; Fig. 2). Before hunting (1995 and 1999), more than half of homeowners in the community (51–60%) typically observed ≥4 deer in a group and the number of deer observed was similar between years ($\rho_{3.0} = -0.099$; $P = 0.175$). One year after hunting was implemented (2001), only 27% of homeowners observed ≥4 deer in a group and typical group size of deer observed in the community declined ($\rho_{3.0} = 0.217$; $P = 0.002$) compared with one year before the hunt. Four years after hunting was implemented (2005), 14% of homeowners observed ≥4 deer in a group and typical group size of deer observed in the community continued to decline ($\rho_{3.0} = -0.178$; $P = 0.007$) compared with 1 yr after the hunt (2001; Fig. 2).

Based on the aerial deer survey, the prehunt (1996–1999) deer densities ranged from 39.8 to 54.5 deer per square kilometer (Table 1). Posthunt (2002–2007) deer densities ranged from 0 to 9.8 deer per square kilometer (Table 1). Sightings of deer groups reported by homeowners were correlated ($r^2 = 1.0$; $P = 0.001$) with aerial deer survey estimates in the community.

Frequency of deer observations in the community differed among years ($\rho_{9.0} = 0.729$; $P < 0.001$; Fig. 3). Before hunting (1995 and 1999), most residents (86–92%) observed deer daily or weekly; however, frequency of observations generally declined from 1995 to 1999 ($\rho_{2.0} = 0.192$; $P = 0.009$). One year after

Table 1. Deer abundance from winter surveys, resident observations of deer, nymphal tick densities, prevalence of infection with *B. burgdorferi*, ERI, and human cases of Lyme disease in the MC community from 1995 to 2007

Year	Winter aerial surveys (km^2)	% residents observing deer daily	% residents reporting group size ≥ 4 deer	Nymphs (SEM)/100 m^2 lawn[a]	Nymphs (SEM)/100 m^2 woods[a]	% infected (n^b)	ERI[c] lawn	ERI[c] woods	Cases of Lyme disease/100 households
1995	54.5	80	59.3						NS
1996	39.8								13.1
1997	NS								14.1
1998	NS								28.8
1999	46.3	58	52.7						18.3
2000[d]	NS								16.3
2001[e]	NS	14		0.91 (0.26)	5.00 (1.22)	18.8 (16)	0.17	0.94	4.8
2002[f]	0			0.79 (0.17)	3.50 (0.81)	12.0 (25)	0.09	0.42	4.6
2003[f]	5.1			0.22 (0.07)	0.33 (0.23)	na	na	na	1.9
2004[f]	5.1			0.18 (0.06)	0.67 (0.36)	12.5 (8)	0.02	0.08	2.8
2005[f]	1.7	<1	16.5	0.35 (0.09)	0.44 (0.31)	11.1 (27)	0.04	0.05	2.8
2006[f]	9.8			0.04 (0.03)	0.50 (0.50)	na	na	na	3.1
2007[f]	6.5			0.54 (0.13)	2.75 (2.76)	10.0 (10)	0.05	0.28	5.2

[a] Nymphal densities are representative of adult tick abundance two years prior. Therefore, nymphal tick densities were compared with deer densities two years prior.

[b] Total number of ticks tested.

[c] Entomological risk index.

[d] Twenty-seven deer removed from two tracts of open space during November controlled hunt.

[e] Twenty-three deer removed from three tracts of open space during November controlled hunt.

[f] Archery hunters removed three to five deer per year.

NS, no survey; na, not available.

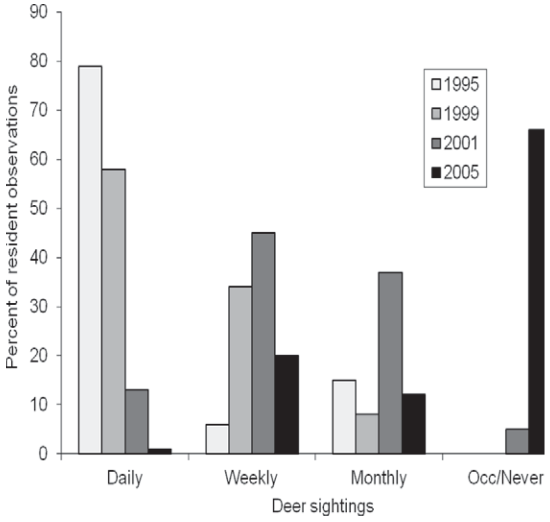

Fig. 3. Frequency of deer sightings by residents in the MC community in Groton, CT, 1995–2005.

hunting was implemented (2001), 58% of residents observed deer daily or weekly and frequency of deer observations declined ($\rho_{4.0} = 0.510$; $P < 0.001$), compared with one year before the hunt. Four years after hunting was implemented (2005), 21% of residents observed deer daily or weekly and frequency of deer observations continued to decline ($\rho_{4.0} = 0.527$; $P < 0.001$) compared with 1 yr after the hunt. Frequency of daily deer sightings by homeowners was correlated ($r^2 = 0.984$; $P = 0.082$) with aerial deer survey estimates in the community.

Mean nymphal tick densities (nymphs per 100 square meter) on lawn edges declined from 2001 to 2002, to 2003, to 2004, and 2006. Pairwise multiple comparisons found significant differences between 2001 and 2003, and 2006, and between 2002 and 2006 ($Q \geq 3.158$; $P < 0.05$). Mean nymphal tick densities increased slightly in 2005 and 2007, but may reflect residuals from the regression model. Nymphal tick density was strongly correlated ($r^2 = 0.717$; $P = 0.016$) with deer density in the community (Fig. 4). Mean tick densities (nymphs per 100 square meter) declined in the wooded plots from 2001 to 2002 to 2003–2004 to 2005–2006 and then rose in 2007 (Table 1). There was no significant difference in overall tick density between the lawn plots and wooded plots over the study period ($t = -2.025$; $P = 0.066$). The ERI for lawns and woods declined 88 and 91% as tick densities decreased (Table 1).

Mean number of resident-reported human cases of Lyme disease in MC declined ($U = 0.0$; $P = 0.004$) from before (= 18.1, SD = 6.3; 1996–2000) to after the hunt (= 3.6, SD = 1.3; 2001–2007). Number of resident-reported human cases of Lyme disease per 100 households was strongly correlated ($r^2 = 0.917$; $P < 0.001$) to deer density (Fig. 5) and daily deer sightings from residents in the community ($r^2 = 0.993$; $P < 0.052$).

Discussion

Our findings support the comments by Wilson et al. (1990) and later authors that in areas with high deer and tick populations and high human activity, significant reductions in the local deer herd should reduce the risk of contracting Lyme disease. Based on physician-based reporting where erythema migrans (EM) rash occurred, Garnett et al. (2011) found no significant reduction in physician-based reported cases of Lyme disease in MC following the hunt, although incidence rates declined 45% from before to after hunting was implemented in the community. The EM rash occurs 80–90% of the time in Lyme Disease cases

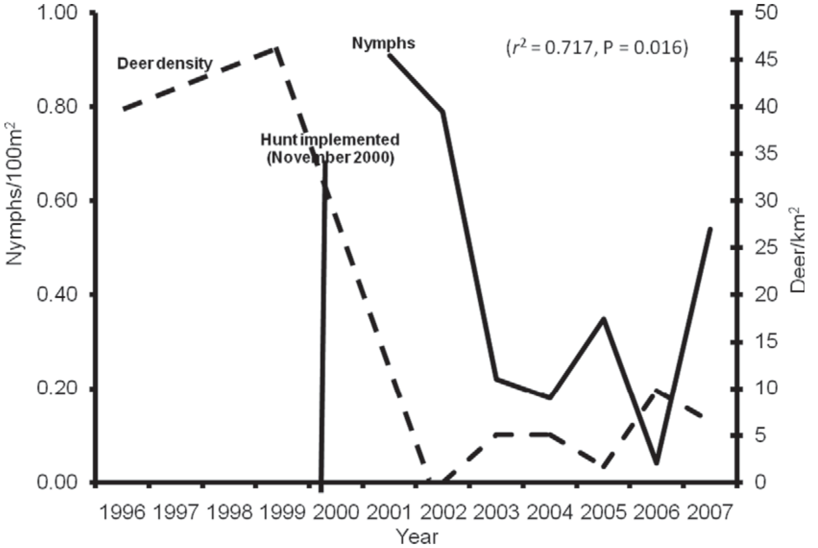

Fig. 4. Nymphal tick density and deer densities in the MC community in Groton, CT, 1996–2007.

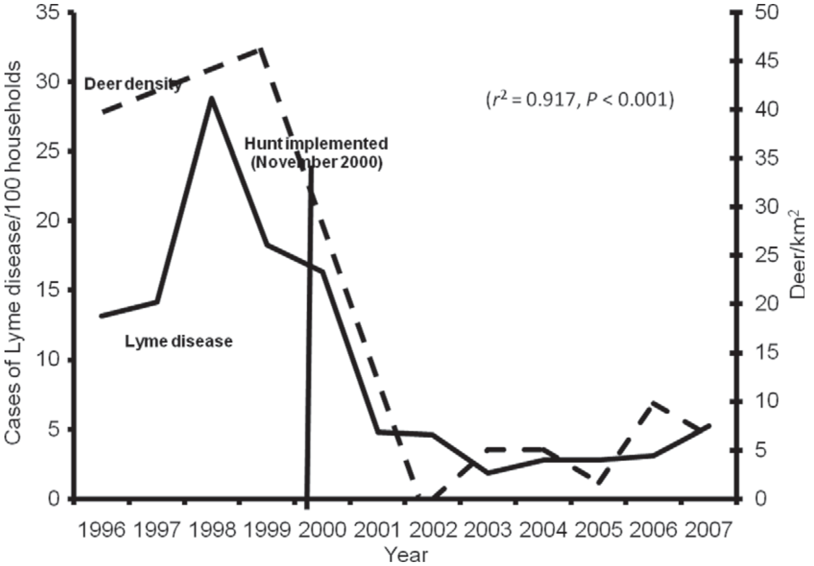

Fig. 5. Reported cases of Lyme disease and deer densities in the MC community in Groton, CT, 1996–2007.

(American Lyme Disease Foundation 2013), so some cases may not have been documented.

In our study, we found that reducing deer density by ≥87% resulted in a significant reduction in tick abundance, nearly a 50% reduction in tick infection rate, and an 80% reduction in resident-reported human cases of Lyme disease. Stafford et al. (1998) found that the ERI was highly variable among years and showed no consistent trend at sites in southeastern Connecticut. However, using the same methods as Stafford et al. (1998), we found the ERI for both lawn and wooded sites in MC declined after hunting began and continued to decline during most years.

In MC, both herd size and frequency of deer sightings by residents declined and remained low after hunting was implemented in the community. Deer density was strongly correlated to frequency and group size of deer observed by residents and resident-reported human cases of Lyme disease in the community. Resident-reported human cases of Lyme disease also was strongly correlated to daily deer sightings by residents and nymphal tick abundance. Similarly, Lastavica et al. (1989) reported that the percentage of households infected with Lyme disease was correlated with daily deer sightings reported by residents in Ipswich, MA. Rand et al. (1996) reported similar findings in Maine, where Lyme seropositivity among dogs increased as the percentage of homeowners reporting daily deer sightings increased. Duffy et al. (1994) found that nymphal ticks were 93% less abundant and larval tick numbers were low to absent in parks on Long Island where deer were absent. Other authors also have found deer density related to tick abundance (Anderson et al. 1987, Wilson et al. 1988, Wilson et al. 1990, Stafford 2001, Stafford et al. 2003), and tick abundance was related to human cases of Lyme disease (Duffy et al. 1994, Stafford et al. 1998).

Deer serve as the primary tick host with ≥90% of adult female *I. scapularis* feeding on deer depending on the availability of other medium-sized mammal hosts (Stafford 2007). Without sufficient deer available, tick populations can't be sustained or are sustained at much lower levels. Our study demonstrated that deer populations can be manipulated to reduce human interactions with deer, infected nymphal ticks, and human risk of contracting Lyme disease. These findings support other observations and conclusions that reduced deer densities should reduce the risk of tick-borne disease in humans (Wilson et al. 1988, 1990; Rand et al. 2003; Stafford et al. 2003, 2007). Although Telford (1993) suggested that deer populations need to be reduced to <3 deer per square kilometer to reduce the zoonotic overflow of Lyme disease to humans, we found that densities of 5.1 deer per square kilometer significantly reduced the number of infected ticks and human risk of contracting Lyme disease. Three years following the initiation of the deer reduction program, infected tick densities (ERI) had been reduced by 88% on residential lawns and by 91% on wooded tracts of open space. With most deer removed during the first 2 yr of this study, our results matched or exceed the 10-yr simulation modeling of the effect of deer reduction on density of *I. scapularis* infected with *B. burgdorferi,* where a 90% reduction in deer yielded 2.5 deer per square kilometer and reduced infected nymphs by 72% (Mount et al. 1997). Our findings and the LYMESIM model (Mount et al. 1997) contradict those of Ostfeld et al. (2006) who used empirical models to conclude that deer abundance was not a determinant of Lyme disease risk. Geographic scale may be a determinant factor. For example, a meta-analysis of deer exclusion studies on ticks found a significant relationship between exclosure size and whether there was tick reduction or increased tick feeding on rodent hosts and pathogen prevalence (Perkins et al. 2006). Deer exclosures >2.5 ha resulted in a reduction of the questing tick population, while those below that size resulted in tick amplification and, as the authors note, tick amplification may be short-lived.

Several studies in which deer densities were greatly reduced noted a temporary rise in questing adult ticks for a 2- to 3-yr period postreduction because there were few deer to feed upon (Wilson et al. 1985, Deblinger et al. 1993, Rand et al. 2004) and a sharp increase in infection rates of remaining ticks (Telford et al. 1988). Although adult ticks were not sampled in this study, we observed no increase in nymphal tick infection rates or increase in human risk of contracting Lyme disease following the deer removal. As expected with the 2-yr tick lifecycle, nymphal tick numbers on the lawn and wooded plots declined by the second and third year following initiation of the controlled hunt. The immediate reduction in cases of Lyme disease in MC could be attributed to fewer deer being available to transport ticks from the woods into residential areas where most residents likely come into contact with ticks. Exposure to Lyme disease often occurs in the vicinity of people's homes, and tick abundance near homes was influenced by extent of deer activity (Steere et al. 1986, Lastavica et al. 1989). An immediate reduction in cases of Lyme disease also could have been attributed to a natural decline related to other ecological factors; however, once Lyme disease cases declined, they remained low because of the low deer densities.

The reduced risk of contracting Lyme disease the year following the hunt may have been enhanced because of the timing and duration of the deer removal. Unlike other studies where deer were removed over a longer period of time (Rand et al. 2004, Wilson et al. 1988), initial removals in MC were conducted over a 2-wk period during the fall (mid-November), when questing by adult ticks is greatest (Stafford 2007). Because no adult tick sampling was conducted, we can only assume that removing a significant portion of the deer herd over a 2-wk period, during peak adult tick activity, removed a large portion of feeding adult ticks and potential hosts for questing adult ticks, lowering breeding success of ticks and reducing tick abundance the following years.

This study provided a unique opportunity to investigate the role of overpopulated deer and the value of deer reduction to reduce human risk of contracting Lyme disease. However, factors such as limited hunter access to deer habitat and movements of deer from adjacent landscapes may reduce success of programs designed to reduce human risk of contracting Lyme disease. Reducing deer populations can be an effective method to reduce human risk of contracting tick-borne diseases in residential communities. Hunting programs led by an ambitious community leader, who is committed to overseeing a deer–tick reduction program is critical to the success of programs of this nature. Additionally good hunter access to deer habitat and a wide variety of management tools (bait, unlimited tags, incentive programs) are important components of a successful deer reduction strategy. Daily deer sightings by residents may be used as a surrogate measure of change in deer density. Reducing deer populations to levels that reduce the potential for ticks to successfully breed should be an important component of any long-term strategy seeking to reduce the risk of people contracting Lyme disease.

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