Effects of Reduced Deer Density on the Abundance of *Ixodes scapularis* (Acari: Ixodidae) and Lyme Disease Incidence in a Northern New Jersey Endemic Area

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ABSTRACT We monitored the abundance of *Ixodes scapularis* Say (Acari: Ixodidae) and the Lyme disease incidence rate after the incremental removal of white-tailed deer, *Odocoileus virginianus* Zimmermann, within a suburban residential area to determine whether there was a measurable decrease in the abundance of ticks due to deer removal and whether the reduction in ticks resulted in a reduction in the incidence rate within the human population. After three seasons, the estimated deer population was reduced by 46.7%, from the 2002 postfawning estimate of 2,899 deer (45.6 deer per km^2) to a 2005 estimate of 1,540 deer (24.3 deer per km^2). There was no apparent effect of the deer culling program on numbers of questing *I. scapularis* subadults in the culling areas, and the overall numbers of host-seeking ticks in the culling areas seemed to increase in the second year of the program. The Lyme disease incidence rate generated by both passive and active surveillance systems showed no clear trend among years, and it did not seem to vary with declining deer density. Given the resources required to mount and maintain a community-based program of sufficient magnitude to effectively reduce vector tick density in ecologically open situations where there are few impediments to deer movement, it may be that deer reduction, although serving other community goals, is unlikely to be a primary means of tick control by itself. However, in concert with other tick control interventions, such programs may provide one aspect of a successful community effort to reduce the abundance of vector ticks.

KEY WORDS *I. scapularis*, deer reduction, Lyme disease risk

Lyme disease has become the most common vector-borne disease in the United States, with some 23,763 cases diagnosed nationwide in 2002 (CDC 2004). The importance of white-tailed deer, *Odocoileus virginianus* Zimmermann, as hosts for the reproductive stage of the blacklegged tick, *Ixodes scapularis* Say (Acari: Ixodidae), the principal vector of Lyme borreliosis in the eastern and midwestern United States, is well documented, and the incidence of Lyme disease seems to be directly related to deer density (Piesman 2002). Because white-tailed deer have become overabundant in many suburban areas (McShea et al. 1997), local governments have conducted or are considering deer reduction programs with greater frequency. Justifications for such programs have included increasing concern for highway and road safety (reduction of deer-vehicle collisions), observed ecological effects due to overbrowsing (replacement of native plants by invasive exotic plants, shifts in mammal and avian diversity), and reducing tick-borne disease risk (Conover 1997, McShea et al. 1997, Côté et al. 2004).

Previous studies have suggested that a reduction in the abundance of *I. scapularis* nymphs would lower the transmission risk to humans (Wilson et al. 1988b, Stafford and Kitron 2002). Although there is evidence to suggest that significant reductions in deer density may reduce numbers of host-seeking *I. scapularis,* virtually all such research has been performed on islands or other geographically isolated areas (for review, see Stafford and Kitron 2002).

Although the importance of deer in tick-borne disease transmission cycles is unquestioned, organized deer population reduction programs remain controversial, and it is important to investigate the impact of deer reduction on the populations of *I. scapularis* and Lyme disease incidence in mainland, ecologically open environments. The objectives of this study were to 1) monitor populations of *I. scapularis* after the incremental removal of deer within a suburban residential area; 2) determine whether there is a measurable decrease in the abundance of ticks due to deer removal, and 3) determine whether the reduction in ticks leads to a reduction in the Lyme disease incidence rate within the human population.

Materials and Methods

Study Area Description. The deer reduction program was conducted in Bernards Township, a 63.5-km^2

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suburban municipality located in northern Somerset County, NJ. Bernards Township is largely rural or semirural, with open space, recreational areas, and farmland making up ≈46% and low-to-moderate density residential development (>0.75-acre lots) another 39.5% of total acreage (Township of Bernards 2003). Residential areas are characterized by extensive tree lines and borders with nearby wooded lots and preserved forest open space.

Study areas consisted of mature second growth mixed hardwood forest typical of the southern Highlands physiographic province of north central New Jersey (Collins and Anderson 1994). The canopy consisted of red oak, *Quercus rubra* L.; chestnut oak, *Quercus prinus* L.; yellow poplar, *Liriodendron tulipifera* L.; sassafras, *Sassafras albidum* (Nutt.) Nees; and sugar maple; *Acer saccharum* Marsh. The understory included the dominant canopy species, in addition to black cherry, *Prunus serotina* Ehrh.; eastern red cedar, *Juniperus virginiana* L.; and hickory (*Carya* spp.).

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 sampled areas. In some deer cull 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. Much of the forested area was characterized by considerable amounts of fallen woody material (branches and trunks).

Deer Reduction Program. The Bernards Township Community-Based Deer Management Plan (CBDMP) included controlled archery hunting by qualified members of two township-authorized private sport hunting groups on designated municipal or Somerset County-owned tracts and controlled shotgun hunting by one of these groups on several designated tracts of municipal and county land. The program commenced in Fall 2001 and involved the annual incremental removal of deer at 12–18 baiting sites in each year. The stated goal of the CBDMP was a reduction of the township deer density to a maximum of 7.7 deer per km^2 (20 deer permi^2) (BTDMAC 2005). A prefawning deer population estimate for Bernards Township was obtained using an April 2002 aerial forward-looking infrared radar census of the entire 63.5-km^2 township. A subsequent postfawning estimate was calculated in July 2002 based on reproduction figures provided by the New Jersey Division of Fish and Wildlife (NJDFW) for Deer Management Zones encompassing the township (BTDMAC 2005). Subsequent annual population estimates were calculated from this original population density, official road kill figures (provided by the Bernards Township Police Department log for municipal and county roads in the Township and estimated for the 24.5 km of interstate highway within the township's borders and for off road deaths), plus the annual private property sport hunting and CBDMP municipal/county property harvest numbers reflected in the NJDFW-recorded total harvest, and the recommended reproductive rate assumption for the area (BTDMAC 2005).

New Jersey is divided into 63 deer management zones (DMZs) that are generally areas with similar land use, land ownership, soils and vegetation, and deer population characteristics. Density estimates were obtained from helicopter surveys. Because only deer visible from the helicopter are counted, the surveys are likely an undercount of actual deer numbers, particularly in areas of dense forest cover and where evergreens obscure visibility. Such aerial counts also represent deer sighted on particular parcels on a given day and time. Thus, all estimates are actually a minimum density for the area. After the last comprehensive state survey, the average minimum statewide deer population density was estimated to be 14.7 deer per km^2. Average deer densities range from 5.0 deer per km^2 in urbanized areas to 29.3 deer per km^2 in heavily forested far western New Jersey (NJDFW 1999). Bernards Township and all of the surrounding control communities are located in either DMZ 9 or 13, both with estimated deer density of 15.4–19.3 deer per km^2 (40–50 deer per mi^2) (NJDFW 1999). No aerial surveys of the control areas were possible as part of this study, so that we accepted NJDFW assumptions of deer densities similar to Bernards Township in the surrounding control areas.

Tick Sampling. We established tick-sampling areas in the vicinity of 10 of the baiting sites (cull sites). An additional 10 sampling areas were established in areas remote from the baiting sites on public natural areas in Morris and Somerset counties that are not hunted (control sites). At each of the 20 tick sampling areas, we established a single 100-m^2 plot placed in areas with a patchy shrub layer (<50% shrub cover) to facilitate collection of subadult ticks that quest at ground level within the leaf litter. In addition, we established a 100-m transect nearby in an area with dense shrub layers more likely to yield adult ticks that quest above the ground on woody vegetation (Schulze et al. 1997). We collected all stages of questing *I. scapularis* by using a combination of walking surveys and drag sampling (Ginsberg and Ewing 1989, Schulze et al. 1997). Tick drags used in this study were constructed of a 1-m^2 piece of light-colored corduroy fastened to a 1-cm-diameter wooden dowel along the leading edge. The apparatus was dragged along side of each investigator by means of a 2-m rope handle attached to the ends of the wooden dowel.

Sampling plots and transects were established in fall 2001 before the anticipated initial deer harvest, and they were sampled three times during each of the subsequent peak activity periods of *I. scapularis* larvae, nymphs, and adults (Schulze et al. 1986). Adults were sampled three times at approximately weekly intervals during late March to early April and again in late October to early November, whereas nymphs and larvae were similarly sampled between mid-May and mid-June and in August, respectively. Walking

Table 1. Annual deer harvest, road kill estimate, and estimate total deer population in Berndards Township, 2002–2005

Yr	Total harvest	Road kill	Total deer killed	Pop estimate
2002 prehunt				2,899 (45.6/km^2)
2002–2003	435	379	814	2,484 (39.9/km^2)
2003–2004	543	356	899	2,120 (33.5/km^2)
2004–2005	641	323	964	1,540 (24.3/km^2)

and dragging surveys were conducted simultaneously between 0800 and 1200 hours by the same individuals, and all cull and control sites were sampled within a 24-h period to minimize any investigator or temporal bias. Ticks adhering to investigators' clothing and drags were removed at 20-m intervals, identified to species and stage, and returned to the plot or transect.

Lyme Disease Surveillance. Since 1981, the New Jersey Department of Health and Senior Services (NJDHSS) has maintained a passive Lyme disease surveillance system in which all physician-diagnosed and laboratory-confirmed cases of Lyme disease are reportable to local health departments (LHDs) having jurisdiction in the municipality where the patient resides. For the purpose of this study, physician offices likely to evaluate potential Lyme disease patients were recruited from Bernards Township and 10 surrounding municipalities to participate in an active surveillance system that more accurately characterized Lyme disease incidence within the study municipalities. Cases generated by both the passive and active surveillance systems were evaluated by the LHD to determine whether they met the Centers for Disease Control and Prevention (CDC) surveillance case definition (CDC 1997). Cases were reported electronically to the NJDHSS via the Communicable Disease Reporting and Surveillance System. This system allows for the capture, retrieval, and analysis of demographic, clinical, and epidemiological data. Confirmed cases of disease are reported via electronic transfer to the CDC. Numbers of confirmed cases from Bernards Township and the 10 surrounding municipalities were obtained from this NJDHSS database.

Statistical Analysis. Differences in numbers of host-seeking ticks were compared among years and between culling and control sites by using repeated measures analysis of variance (ANOVA) on log-transformed tick abundance and Tukey's honestly significant difference (HSD) tests (Sokal and Rohlf 1981). Lyme disease case numbers were converted to incidence rates (cases per 100,000) and compared between Bernards Township and the surrounding communities by using repeated measures ANOVA and compared with annual tick abundance by using simple linear regression. Tests of normal assumptions and all statistical tests were performed using STATISTICA analysis packages (StatSoft 1995).

Results

Deer Reduction. The 2002 postfawning deer count for Bernards Township was 2,899 deer or 45.6 deer per km^2 (BTDMAC 2005) (Table 1). During 2002–2003, controlled hunting removed 258 deer and an additional 177 deer were known to have been taken by local, invited sports hunters on private lands, for a total of 435 deer killed. An additional 379 deer were killed in vehicle collisions. The two authorized sport-hunting groups killed 251 deer during the 2003–2004 season. The NJDFW recorded an additional 292 deer killed on private lands for a total of 543 deer killed in the township for the 2003–2004 season. The estimated total road kill for 2003–2004 was 356 deer. Authorized hunters took a total of 304 deer from designated cull areas during the 2004–2005 season, representing an increase of 21% over the previous year. The NJDFW counted an additional 337 deer killed on private lands for a total 641 within the township. The estimated total road kill for 2004–2005 was 323 deer. After three seasons, the Township's estimated deer population was reduced by 46.7% to a current estimate of 1,540 deer (24.3 deer per km^2).

Tick Collections. Host-seeking ticks at the cull tracts were significantly less abundant than at the control sites for all active stages and in all years (Table 2). Numbers of spring adults at the culling sites did not differ significantly in 2004 and 2005 from preintervention numbers. Nymphal abundance was significantly reduced in the cull areas in 2004, but it had rebounded to previous levels the following year. Also, numbers of host-seeking larvae in the cull sites were actually higher in the two summers after the start of deer culling and numbers of host-seeking fall adult ticks at the culling tracts were actually three-fold higher in 2005 than in previous years. There was no apparent effect of the deer-culling program on numbers of questing *I. scapularis* subadults in the culling areas, and the overall numbers of host-seeking ticks in the

Table 2. Results of ANOVA comparing tick abundance (mean ± SE) at 10 cull and 10 control sites between years 2002–2005

Life stage	Yr								ANOVA results
	2002		2003		2004		2005		
	Cull sites	Control sites	Cull sites	Control sites	Cull sites	Control sites	Cull sites	Control sites	
Spring adults	1.2 ± 0.2a	4.9 ± 0.8b	1.3 ± 0.2a	4.8 ± 0.8b	0.9 ± 0.1a	2.3 ± 0.3a	3.6 ± 0.3b	5.1 ± 0.3b	$F = 16.92, P < 0.01$
Nymphs	1.5 ± 0.2a	2.5 ± 0.2b	1.5 ± 0.2a	2.6 ± 0.2b	0.8 ± 0.1c	2.3 ± 0.3b	2.1 ± 0.3a,b	4.0 ± 0.3d	$F = 13.89, P < 0.01$
Larvae	6.7 ± 0.7a	37.7 ± 6.0b	3.9 ± 0.6c	34.7 ± 5.8b	12.9 ± 0.8a	45.0 ± 6.0b	16.1 ± 0.9a	48.0 ± 5.9b	$F = 16.22, P < 0.01$
Fall adults	1.5 ± 0.2a	6.5 ± 0.9b	1.1 ± 0.2a	4.3 ± 0.5c	1.2 ± 0.3a	6.4 ± 0.3b	3.6 ± 0.4c	7.9 ± 0.4b	$F = 28.18, P < 0.01$

Numbers in the same row followed by the same letter are not significantly different ($P < 0.05$; Tukey's HSD test).

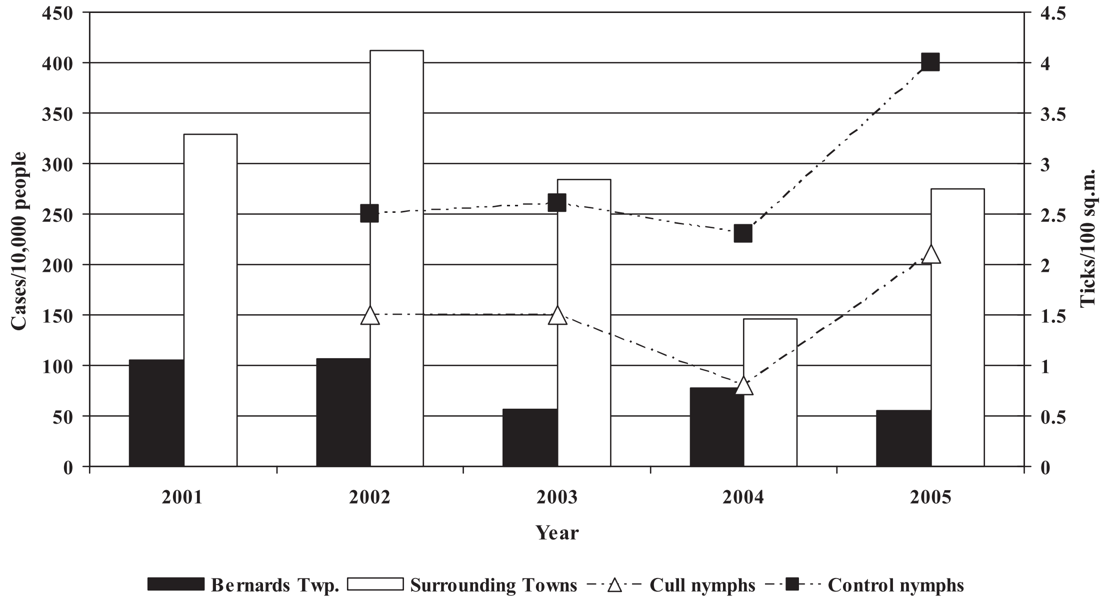

Fig. 1. Lyme disease incidence rates (cases per 100,000 people) in Bernards Township and mean incidence rate for 10 surrounding municipalities (bars) during the period 2001–2005; mean nymphal *I. scapularis* abundance ± SE at deer culling and control areas (lines) for the period 2002–2005.

culling areas seemed to increase in the second and fourth years of the program.

Lyme Disease Surveillance. The Lyme disease incidence rate in Bernards Township and in the 10 surrounding municipalities showed no clear trend among years (Fig. 1). Although the incidence rate in Bernards Township dropped by 47.2% (from 107.3 to 56.6 case/100,000) between 2002 and 2003, it increased by 37.9% in the next year to 78.1 cases per 100,000, suggesting no effect of the culling program initiated in 2002. Incidence rate in Bernards Township did not seem to vary with declining deer density ($r = 0.68$, $P = 0.68$) and linear regression of nymphal tick abundance on incidence rates was not significant ($R^2 = 0.39$; $F_{1,6} = 3.91$; $P = 0.09$).

Discussion

Three seasons of controlled hunting reduced the density of white-tailed deer within Bernards Township by 46.7%, from a preintervention estimate of 45.6 deer/km^2 to a 2004–2005 estimate of 24.3 deer per km^2. Abundance of host-seeking ticks in the hunted areas showed little annual variation and increased in the final year of the study. Host-seeking ticks at the cull tracts were significantly less abundant than at the unhunted control sites for all active stages and in all years. Although plots and transects were established in cull areas where the habitat seemed suitable to support ticks (Schulze et al. 1991), presence of more extensive and contiguous habitat, demonstrating less damage by deer browsing, may have contributed to larger numbers of ticks at control sites. Nevertheless, annual collections of host-seeking *I. scapularis* at the culling areas indicated that deer reduction efforts had no apparent effect on the numbers of ticks. In addition, there was no significant difference in mean incidence rates between Bernards Township and the surrounding municipalities over the course of the study and no apparent relationships between incidence rates and either deer population density or nymphal tick abundance.

Although host removal has been used successfully in suppression of southern cattle ticks, *Boophilus microplus* (Canestrini) (Wilkinson 1957), and *Ixodes ricinus* L. (on sheep) (Randolph and Steele 1985) in controlled pastureland, the results of deer reduction experiments directed toward reducing *I. scapularis* abundance have been mixed. A 50% reduction in deer density at Great Island, a 240-ha coastal peninsula near Cape Cod, MA, resulted in no measurable decline in subadult tick density (Wilson et al. 1984). However, the near eradication of deer from the same area resulted in a significant reduction in the numbers of nymphal ticks (Wilson et al. 1988a, 1988b). Deblinger et al. (1993) gradually reduced deer density over 7 yr at a 567-ha barrier island site in Massachusetts (from ≈28 to seven deer per km^2), which reduced *I. scapularis* larval and nymphal burdens on white-footed mice by ≈50%. However, the number of ticks on deer increased four- to six-fold during 7 yr of deer reduction at a second site. Finally, a reduction of deer density on a 176-ha fenced forested property in Connecticut from 97.3 to 13.1 deer per km^2 over 7 yr (86.5% reduction) resulted in a five-fold decline in nymphal tick abundance (Stafford and Kitron 2002).

It seems that, at least in geographically isolated or fenced areas, tick populations can be suppressed through intensive efforts to reduce deer population density. Where there are locally high deer densities, large tick populations, and substantial human activity, reducing deer numbers has been suggested as a means of mitigating Lyme disease risk (Wilson et al. 1990, Telford 2002). In a Rhode Island study, Anderson et al. (1987) suggested that removing deer from islands could interrupt the Lyme disease transmission cycle. Observations from the Great Island study suggested that reducing deer density to three deer per km^2 might suppress tick abundance sufficiently to interrupt the tick-human disease transmission cycle (Telford 1993). Kilpatrick and LaBonte (2003) found a significant correlation between the number of physician-diagnosed cases of Lyme disease (as reported in a survey of residents) and deer population size during a deer reduction program at Mumford Cove, CT. Stafford (2001) studied deer populations at two geographically isolated sites in Connecticut and showed a decline in Lyme disease cases as the density of deer was reduced from >77 per km^2 to fewer than 15 deer per km^2. However, the number of cases was reduced only to levels recorded in surrounding towns with similar deer densities and host-seeking ticks remained abundant. Thus, the precise relationships between deer density, tick abundance, and Lyme disease incidence remain unresolved (Rand et al. 1996, Daniels et al. 1998). Moreover, Ostfeld et al. (2006) showed that three-fold variation in deer abundance had no affect on subsequent nymphal *I. scapularis* abundance and suggested that, below a threshold level of abundance, deer density has little overall effect on nymphal density.

Stafford et al. (1998) demonstrated that Lyme disease incidence closely parallels the abundance of host-seeking nymphal *I. scapularis.* However, published deer reduction studies suggest that deer populations would have to be reduced to very low numbers before any resulting decline in tick density could potentially impact disease transmission risk. Actually, 10-yr simulation using the LYMESIM computer model of *I. scapularis* population dynamics showed that reducing deer density from an initial 25 to 0.25 deer per km^2 reduced the number of *B. burgdorferi*-infected nymphs by 98% (Mount et al. 1997). However, such a dramatic reduction in deer abundance would be difficult to achieve in areas that are not geographically isolated. At the present rate of herd reduction in Bernards Township, the target deer density of $\approx$7.7 deer per km^2 will not be reached for another 4–5 yr, and it is not clear that this deer density will achieve significant tick reduction. Any decision to maintain an ungulate population at a desired cultural carrying capacity (sensu Minnis and Peyton 1995) short of its natural limits also would require an indefinite commitment to management actions, because populations may rapidly respond to relaxation of control efforts (Gogan et al. 2001). Such extensive and long-term culling programs are controversial and may increase conflict among wildlife agencies, hunters, and animal welfare advocates (Schmidtmann 1994). Finally, suburban use of forest landscapes seem to have increased food resources for deer, while reducing vulnerability to hunting, thus increasing herd size (Roseberry and Woolf 1998). Consequently, unless significant changes are made to the way that residential landscapes are managed, deer population reduction is likely to be a long-term commitment. Given the resources required to mount and maintain a community-based deer reduction program of sufficient magnitude to effectively reduce vector tick density in ecologically open situations where there are few impediments to deer movement, it may be that such a program, although serving other goals such as landscape protection and reduction in deer-car collisions, is unlikely to be a cost-effective (Duffy et al. 1994) or publicly accepted (Stafford and Kitron 2002) means of tick control by itself. However, in concert with short-term tick control interventions, including habitat- and host-targeted acaricide applications and personal protection (Schulze and Jordan 2006) and longer term interventions, such as vegetation management and public education, and where the community is willing to commit to a long-range deer management to meet other societal goals, such programs may provide one aspect of a successful community effort to reduce the abundance of vector ticks.

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