

Temporal Relation between *Ixodes scapularis* Abundance and Risk for Lyme Disease Associated with Erythema Migrans

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Understanding the role that nymphal and female ticks, *Ixodes scapularis*, have in the epidemiology of Lyme disease is essential to the development of successful prevention programs. In this study, the authors sought to evaluate the seasonal and annual relations between tick densities and patients ≥ 16 years of age diagnosed with erythema migrans (EM), the rash associated with early Lyme disease. Ticks were collected weekly by drag sampling throughout most of the year from 1991 to 1996 in Westchester County, New York. The number of EM cases was based on patients diagnosed at the Westchester County Medical Center using Centers for Disease Control and Prevention (CDC) criteria. No patients with EM were diagnosed from January through April, when only adult ticks were active. Correlation analysis between monthly tick densities and EM incidence was significant for nymphs ($r = 0.87$, $p < 0.01$), but not for adult ticks ($r = -0.57$, $p > 0.05$). There was a strong, although not significant, correlation between peak annual number of patients with EM and peak nymphal tick abundance ($r = 0.76$, $p = 0.08$). These data indicate that bites from adult *I. scapularis* only rarely result in Lyme disease, and that annual nymphal tick abundance determines exposure. This suggests that annual fluctuations in Lyme disease case numbers are largely due to natural changes in tick abundance and, therefore, that control of nymphal *I. scapularis* should be a major component of Lyme disease prevention efforts. *Am J Epidemiol* 1999;149:771–6.

Borrelia; erythema migrans; *Ixodes*; Lyme disease; ticks

Lyme disease, a tick-borne infectious disease first described clinically in 1977 (1), is the most commonly reported vector-borne disease in the United States (2). Nationally, the incidence of Lyme disease is increasing, with 16,461 cases reported from 45 states during 1996 (3). The causative agent of Lyme disease, *Borrelia burgdorferi* sensu lato (4), is transmitted to humans and domestic animals through the bite of ticks in the *Ixodes persulcatus* group (5, 6). Over 90 percent of cases reported in the United States are from the Northeast, Mid-Atlantic, and Upper-Midwest (7), where the vector is the blacklegged tick, *I. scapularis* (formerly *I. dammini*) (8).

Early Lyme disease usually presents with a characteristic skin rash known as erythema migrans (EM)

which occurs days to weeks after the bite of an infected deer tick; the average incubation time period is one week (9, 10). Clinical characteristics of EM may be variable, yet it typically manifests as a reddish papule originating at the site of the tick bite and rapidly enlarges over a period of days (11, 12). Associated symptoms of early Lyme disease may include arthralgia, myalgia, headache, fatigue, and fever (12). Weeks to months after infection, the cardiac, neurologic, and musculoskeletal systems may be involved, particularly in untreated patients (11, 13).

Not all life stages of *I. scapularis* are important vectors of *B. burgdorferi*. Immature larval ticks, the first active developmental stage, are rarely infected with the spirochete and are not known to transmit infection (14). Adult male ticks do not feed sufficiently long enough to allow spirochete transfer and rarely attach to humans; therefore they, too, are not considered vectors (15). Immature nymphs and adult female ticks, however, can efficiently transmit *B. burgdorferi* (5). Studies that address the epidemiology of human exposure to Lyme disease must therefore address the ecology and temporal distribution of nymphal and female *I. scapularis*.

The accuracy of data pertaining to human exposure to *B. burgdorferi* is extremely important, because

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Abbreviations: EM, erythema migrans; LDDC, Lyme Disease Diagnostic Center; WCMC, Westchester County Medical Center.

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such information is often incorporated into public health recommendations to reduce Lyme disease incidence through tick-bite prevention (16, 17) and vector control (18, 19). Although Lyme disease, as measured by reports of patients with EM, is acquired primarily during the summer months, when nymphal ticks are abundant (20–22), disease transmission has also been reported during the spring and fall, when nymphal ticks are inactive and female ticks are most active (22). However, accurate assessments of the role that nymphal and female *I. scapularis* have in the epidemiology of Lyme disease are difficult to determine because such studies require labor-intensive field sampling to gather accurate data on local tick abundance (23, 24). Additionally, these studies often rely on cases of Lyme disease reported to local health authorities, which are subject to the inaccuracy and inconsistency associated with such reporting (25, 26).

Measurement of seasonal and annual changes in *I. scapularis* abundance with respect to the annual incidence of EM is epidemiologically important. Accurate assessments of such relations would assist public health efforts to define factors that influence human exposure to Lyme disease. Furthermore, the relation between tick density and EM may serve as an indicator of the success of public health strategies in preventing and controlling Lyme disease. Currently, it is not known whether changes in annual EM reports reflect varying effectiveness of such strategies or to natural variation in tick abundance from one year to the next.

The purpose of this study was to evaluate further the association between seasonal changes in nymphal and female *I. scapularis* densities and EM incidence, and to examine the relation between annual changes in nymphal *I. scapularis* abundance and the diagnosis of EM.

MATERIALS AND METHODS

Selection of EM cases

The Westchester County Medical Center (WCMC), located in Valhalla, New York, is in the southern region of the state, where Lyme disease is endemic (20). *I. scapularis* is common in both residential (27) and recreational (23) areas of Westchester County, and it is also the most prevalent tick which parasitizes humans (15).

The WCMC has operated a Lyme Disease Diagnostic Center (LDDC) since 1989 for the purpose of diagnosing and treating new cases of Lyme disease. During the course of this study, the LDDC offered walk-in evaluation four evenings per week during

June, July, and August, and one evening per week for the remaining months of the year. The clinic, located in central Westchester County, is open to the public with no geographic restrictions, although approximately two-thirds of patients reside in Westchester County. A sliding-scale billing arrangement and access to public transportation assure that care is available to all socioeconomic groups. Public awareness of the facility is achieved through newspaper and radio advertisements, as well as by referral from local physicians and health departments.

The EM cases reported in this study represent those patients diagnosed at the LDDC over a 6-year period, from January 1, 1991 through December 31, 1996, and who met the Centers for Disease Control and Prevention (CDC) surveillance criteria of an EM that measures at least 5 cm in size (28). Patients were 16 years of age or older and received a thorough clinical examination with full skin visualization at the time of initial visit. All cases of EM were confirmed by at least one of six infectious disease specialists experienced in the diagnosis and treatment of Lyme disease. Monthly cases of EM diagnosis were totalled for each year and were used to establish the seasonal (intra-year) and annual (inter-year) distribution of EM cases seen at the LDDC.

Determination of *I. scapularis* abundance

Abundance of host-seeking nymphal and adult *I. scapularis* ticks was determined at a wooded site in central Westchester County, located approximately 16 km from the LDDC. The tick population at this site has been monitored since 1984 and has been shown to harbor an increased population of immature deer ticks (29).

Ticks were collected by drag sampling, which involved pulling a 1-m² piece of white flannel cloth over leaf litter and vegetation. The cloth was checked every 20 m for the presence of ticks (23, 24). Any ticks found clinging to the cloth were preserved in 70 percent alcohol for later identification. Drag sampling has been determined to be the most efficient method of collecting *I. scapularis* in this area (24).

Each sampling session consisted of drag sampling randomly selected transects within a 60 × 60 m study grid. Sampling was conducted two to three times per week from March through December, weather permitting. A total of 500 m² was sampled in each drag. Therefore, a total of 1,000 to 1,500 m² was usually sampled each week throughout the 6-year period of this study. Monthly mean densities for nymphal and adult ticks were calculated. These densities were used to determine the seasonal relations between tick abundance and EM incidence.

Population estimates of nymphal *I. scapularis*

Although drag sampling is effective in determining seasonal trends and the relative abundance of *I. scapularis* in an area (22, 24), it underestimates the absolute number of ticks (30). To accurately monitor annual changes in absolute nymphal *I. scapularis* abundance, a mark-release-recapture study was conducted each year during the period of peak nymphal abundance (27, 31, Daniels et al., unpublished). Ticks collected in a 1,400 m² area were marked with fluorescent powder or paint pens and released at the site of capture. Subsequent sampling permitted identification of previously marked and unmarked ticks. Population estimates were then calculated using the Schnabel method (32).

Statistical analysis

The seasonal relation between tick abundance and EM diagnosis was examined from year-to-year. Monthly numbers of EM cases were compared to the monthly nymphal and female tick densities by correlation analysis for the 6-year period. Similar testing was conducted for individual years from 1991 through 1996. In all analyses, the Kolmogorov-Smirnov test was used to test for normality (33).

To determine the relation between annual changes in tick density and the number of EM cases, nymphal population estimates and peak monthly EM numbers were compared by correlation analysis for the years 1991 to 1996.

To determine the effect of increasing clinic operation to 4 days per week during June, July, and August, from Tuesday-only hours during the remaining months, analysis was performed to insure that data from Tuesday were representative of the other clinic days. Correlation analyses between annual peak monthly EM and Tuesday-diagnosed EM also were performed.

RESULTS

Temporal distribution of EM

A total of 450 EM's were reported to the LDDC during the 6-year study period. EM was diagnosed during all months except January, February, March, April, and December (figure 1). During the 7 months of the year in which EM was reported, cases were most frequently diagnosed in July ($n = 212$) and June ($n = 122$), and least often in November ($n = 1$) and October ($n = 3$). The mean (standard error) number of EM's from 1991 to 1996 was 75 (12.1), with annual totals ranging from 33 in 1995 to 105 in 1994 (figure 2).

A total of 121 EM's (26.9 percent) were reported on Tuesdays. Analyses confirmed that the number of EM cases diagnosed on Tuesdays was correlated with the number of cases diagnosed during the entire month ($r = 0.93$, $p < 0.01$). Furthermore, the correlation between annual peak monthly EM's and those EM's diagnosed only on Tuesdays also was significant ($r = 0.86$, $p < 0.05$). Thus, increasing clinic operation to 4 days per week during June, July, and August did not significantly affect the seasonal and annual trends in EM diagnosis.

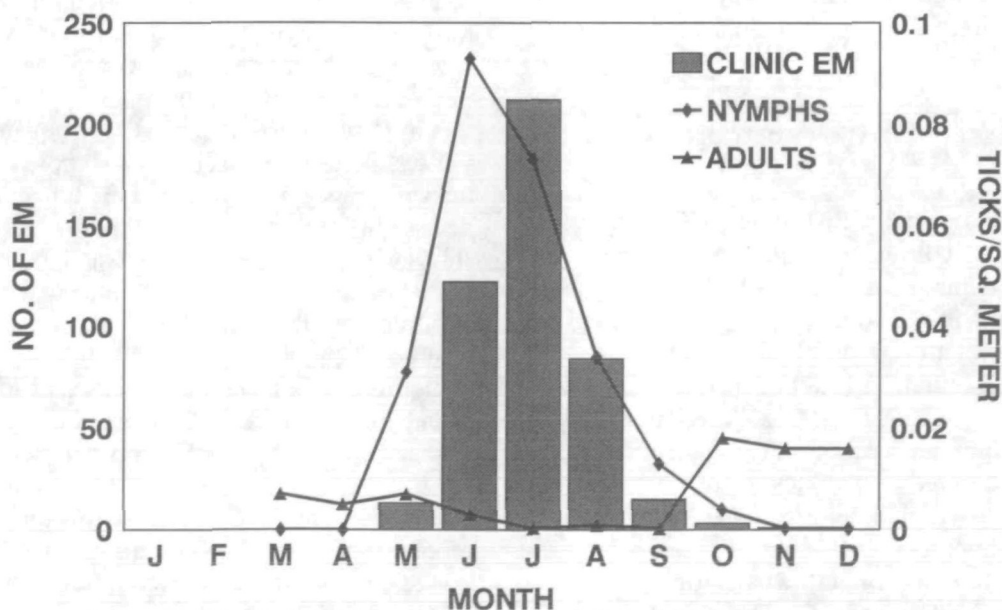


FIGURE 1. Monthly abundance of nymphal and adult *I. scapularis* measured in central Westchester County, New York, and the monthly distribution of erythema migrans (EM) cases diagnosed at the Westchester County Medical Center, 1991–1996.

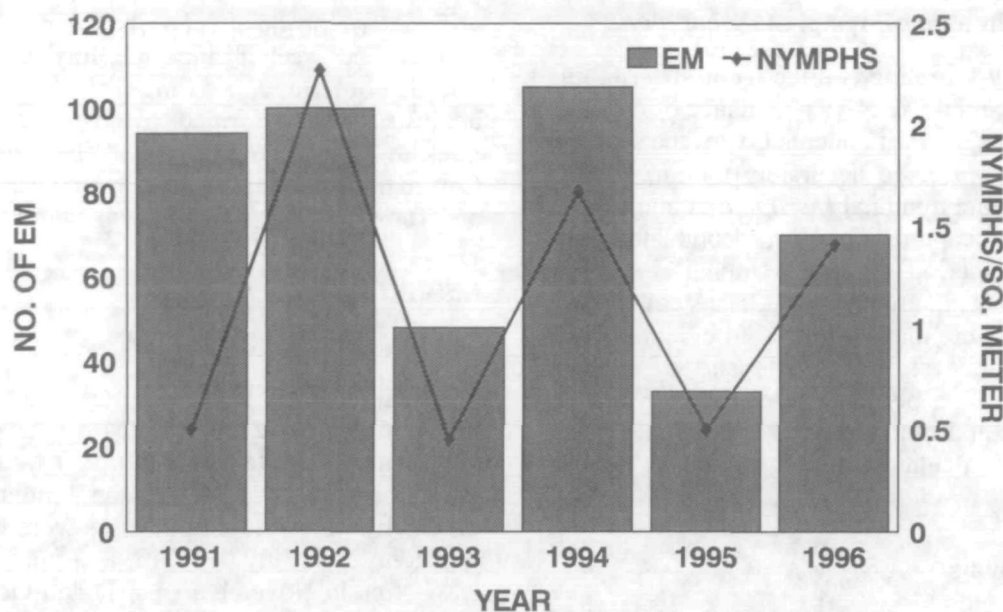


FIGURE 2. Annual nymphal *I. scapularis* density measured in central Westchester County, New York, and annual numbers of erythema migrans (EM) cases diagnosed at the Westchester County Medical Center, 1991–1996.

Temporal distribution of *I. scapularis*

Nymphs were collected during all months except March and April (sampling was not conducted during January and February), females were collected during all months sampled. On average, peak abundance occurred during June for nymphs (0.093 nymphs/m²) and during October for females (0.018 females/m²) (figure 1).

Annual peak nymphal density, as measured by mark-release-recapture population estimates, ranged from 0.45 nymphs/m² (1993) to 2.27 nymphs/m² (1992) (figure 2).

Annual and seasonal relations between ticks and EM

All data were normally distributed (Kolmogorov-Smirnov test, $p > 0.05$). Correlation analysis between monthly nymphal abundance and total monthly EM's diagnosed at the LDDC from 1991 to 1996 resulted in a significant correlation ($r = 0.87$, $p < 0.01$). The correlation between female tick abundance and EM was not significant ($r = -0.57$, $p > 0.05$). Correlation analyses of seasonal tick abundance and EM for individual years revealed a range of r values, from 0.70 in 1992 to 0.97 in 1993 (nymphs), and from -0.44 in 1994 to -0.58 in 1996 (females).

Because of the significant association between nymphal activity and seasonal EM incidence, nymphal density, as estimated by mark-release-recapture experiments, also was compared with annual EM diagnosis.

The relation between peak annual nymphal density and the annual peak monthly EM total resulted in a strong, but not statistically significant, correlation ($r = 0.76$, $p = 0.08$).

DISCUSSION

These results clarify the role of nymphal and female *I. scapularis* in the epidemiology of Lyme disease in southern New York State. Although it has been widely reported that nymphs are the primary vector of Lyme disease in the northeastern United States, adult ticks often are considered to have an important role as vectors of *B. burgdorferi* during the spring and fall seasons. For example, Schulze et al. (34) reported that adult deer ticks play a significant role in the transmission of Lyme disease in New Jersey during these seasons. Couch and Johnson (35) reported that almost 20 percent of reported Lyme disease cases are attributable to adult ticks. Steere (13) reported that adult ticks occasionally transmit the disease when they feed in the autumn.

Our results indicate that no cases of EM in this highly endemic area were diagnosed during the months of January, February, March, and April, when only adult ticks are active, or December, when nymphal activity is negligible. This is in contrast to other studies which reported occasional EM during these months (e.g., 20–22). These studies, however, relied on epidemiologic data derived from physicians who reported to local and state health departments. Such results should be viewed with caution, because overdiagnosis of Lyme

disease, including misdiagnosis of EM, has been reported (25, 26). Data in this study, based on EM confirmed by infectious disease specialists practicing in a Lyme disease endemic area, suggest that risk during these months is negligible. Because of the similarity between EM and other dermatologic processes, such as cellulitis, tinea, and arthropod bite reactions (36), misdiagnosis in these epidemiologic studies must be considered. As a result, the role of adult *I. scapularis* in transmitting *B. burgdorferi* would therefore be overestimated. Our results confirm that the bites from adult female *I. scapularis* only rarely result in cases of EM in adult patients.

Because children under 10 years of age account for more female tick bites than any other age group (15), and because female ticks usually remain attached to children longer than to adult bite victims (37), female ticks may be more important in transmitting spirochetes to this group. Our study excluded children under age 16 years, therefore, we may have underestimated the risk posed by adult ticks to children. However, in a prospective study of Lyme disease in children from southeastern Connecticut, Gerber et al. (38) reported that 89 percent of patients with early localized disease were diagnosed during the months of June, July, and August. These results suggest that EM in children follows the same seasonal pattern as that for adult patients. Thus, including patients younger than age 16 years would not be expected to significantly affect the overall conclusions of this study. Further research, however, is needed to clarify the role of adult *I. scapularis* in the transmission of *B. burgdorferi* to children during the spring and fall months.

Annual fluctuations in EM cases diagnosed at the WCMC during the 6-year study period appeared to be related to nymphal density. Since 1991, EM diagnosis declined during two periods—from 1992 to 1993 and from 1994 to 1995. This represented decreases of 52.0 percent and 68.6 percent, respectively. Nymphal tick density also declined during those years, with reductions of 80.2 percent from 1992 to 1993 and 70.1 percent from 1994 to 1995. These were also the only two periods which showed a decline in nymphal density.

Since 1992, EM cases diagnosed at the WCMC and nymphal tick abundance in central Westchester County have alternated between high and low years. This pattern suggests the possibility that tick abundance, and therefore exposure to *B. burgdorferi*, are influenced by as yet unidentified abiotic (e.g., weather) and biotic (e.g., host density) factors whose roles in regulating tick populations have not been defined.

Correlation analysis between annual peak monthly EM total and annual peak nymphal density resulted in a relatively high r value of 0.76 with a significance value of 0.08. Lack of significance at the $p = 0.05$ level

is likely due to the small sample size and to the large discrepancy between nymphal density and EM's diagnosed during 1991, the first year of the study. In fact, if this year is eliminated from the analysis, the result is statistically significant ($r = 0.95$, $p = 0.02$).

During 1991, nymphal density was low (0.5 nymphs/m²) while the number of EM cases was relatively high ($n = 94$) (figure 2). This anomaly suggests that factors other than tick abundance may also contribute to the public's risk of exposure to tick bites. Environmental factors such as rainfall may also play a role. For example, total weekend precipitation during June and July 1991, as measured at the Westchester County Airport, in central Westchester County, was only 0.81 inches (2.06 cm) of rain, which fell on 2 days (39). This was 27.4 percent less than the next highest year (1993), when 1.10 inches (2.79 cm) of rain fell on 4 days, and 77.9 percent less than the highest year (1996), when 3.67 inches (9.32 cm) of rain fell in 6 days (40, 41). Although nymphal *I. scapularis* densities were low in 1991, the relatively good weekend weather that year may have heightened exposure to *B. burgdorferi* by increasing the level of outdoor activities that brought people into contact with infected ticks. Further research is necessary to define more clearly these relations so that the nature of exposure to tick bites and *B. burgdorferi* can be better understood.

Although previous reports have suggested a link between annual and seasonal Lyme disease incidence and tick density (3, 42, 43), we believe our study is the first to present data from both field and clinical studies. We compared absolute tick abundance, based on mark-release-recapture studies, with EM diagnosed solely by infectious disease specialists experienced in Lyme disease. The correlation between nymphal abundance and EM cases suggests that nymphal activity continues to regulate exposure to *B. burgdorferi* and that public health efforts to reduce Lyme disease incidence in this endemic area have not effectively counteracted increases in tick numbers.

These results underscore the need for public health officials to address the issue of Lyme disease risk reduction by nymphal tick control as *I. scapularis* populations increase in established areas (29) and expand into new sites (44). Control of nymphal ticks (19, 45, 46), as well as innovative educational approaches designed to reduce exposure to nymphal tick bites, should be a major component of Lyme disease prevention efforts.

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