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ABSTRACT From 1998 to 2003, 4,935 hunter-killed deer in northern and central Illinois were examined for ticks; 4,066 blacklegged ticks, *Ixodes scapularis* Say, and 6,530 winter ticks, *Dermacentor albipictus* (Packard) (Acari: Ixodidae), were collected. *I. scapularis* was the predominant tick species in the northern portion of the study area, with a decreasing north-to-south prevalence gradient. In contrast, *D. albipictus* was more common in the south with a decreasing south-to-north prevalence gradient. Compared with previous studies, the geographic range for both species expanded into the central portion of the Illinois River. Prevalence and intensity of both tick species were greater on bucks, and infested bucks were geographically more widespread than infested does and fawns. These findings indicate that blacklegged tick and winter tick distributions remain dynamic in the north central United States

KEY WORDS *Ixodes scapularis*, *Dermacentor albipictus*, white-tailed deer, Illinois, establishment

Although practically extinct in Illinois at the turn of the 20th century (Nixon et al. 1991), the white-tailed deer, *Odocoileus virginianus* Zimmermann, recovered due to highly successful conservation efforts. Unfortunately, the emergence of the blacklegged tick, *Ixodes scapularis* Say, seems to be a consequence of deer population recovery throughout the eastern United States (Spielman 1988). Deer are the principal hosts for adult *I. scapularis* (Piesman et al. 1979, Piesman 2002); tick abundance is positively correlated with deer density (Wilson et al. 1985, 1990; Rand et al. 2003), and the removal of deer (through exclusion or elimination) results in dramatic reductions in immature *I. scapularis* populations (Wilson et al. 1988, Daniels et al. 1993, Deblinger et al. 1993, Stafford 1993). The one-host winter tick, *Dermacentor albipictus* (Packard), also has probably benefited from deer population recovery, particularly in areas such as Illinois where deer are the sole wild ungulates and as a result, the tick's principal host (Demarais et al. 1987; Samuel and Welch 1991; Welch et al. 1991; Kollars et al. 1997, 2000).

In the north central United States, *I. scapularis* was first detected in northwestern Wisconsin in 1968 (Jackson and DeFoliart 1970) and in subsequent years, the tick was found throughout Wisconsin (Godsey et al. 1987, French et al. 1992, French 1995, Riehle and Paskewitz 1996), and Minnesota (Drew et al. 1988, Weisbrod and Johnson 1989). *I. scapularis* was discovered in the late 1980s in northern Illinois (Bouseman et al. 1990), and new foci were detected during the 1990s as the geographic distribution of the blacklegged tick expanded in the northern portion of the state (Guerra 2000, Cortinas et al. 2002). Usually, foci have been found associated with forested riparian corridors (Bouseman et al. 1990, Kitron et al. 1991).

Here, we summarize hunter-killed deer infestation data collected between 1998 and 2003 from the Rock and Illinois rivers. Examining hunter-killed deer is an efficient and relatively inexpensive way of assessing tick distribution over large areas (French et al. 1992, Rand et al. 2003) and of examining geographic range expansion over time (Rand et al. 2003). Our study focused on the Illinois River because *I. scapularis* foci were found on the northern part of the river by 1998 (Kankakee, Will, and La Salle counties), and an *I. scapularis* habitat suitability model (Guerra et al. 2002) predicted that suitable forested habitat was present along the entire length of the river. Forests are relatively continuous along the ≈450-km length of the river, providing a corridor for animal dispersal and migration, and possibly a conduit for the spread of blacklegged ticks.

Our objectives were to describe the geographic distribution of adult *I. scapularis* and *D. albipictus* on white-tailed deer, and, for *I. scapularis,* to compare our findings to surveys that were conducted in the late 1980s (Bouseman et al. 1990).

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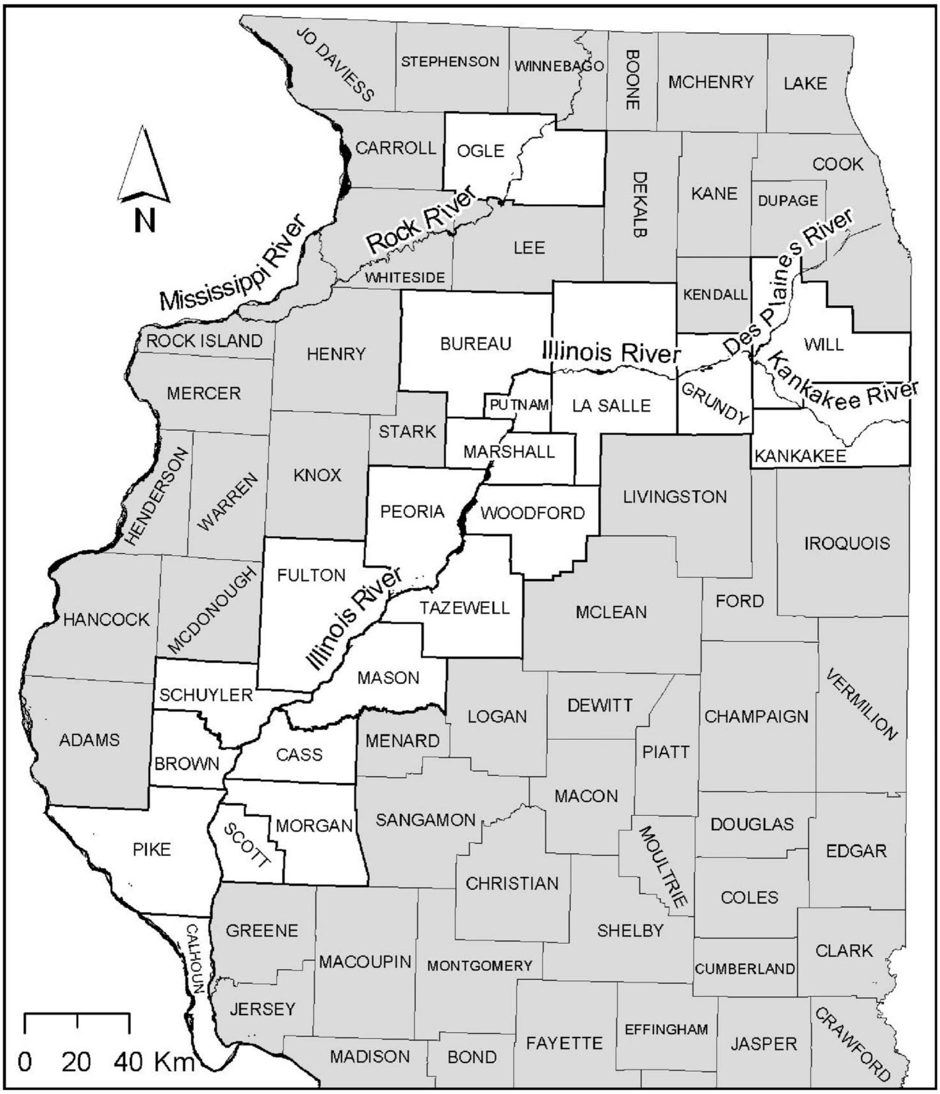

Fig. 1. Map of the study area. Harvest counties where 30 or more deer were examined in at least one of the 5 yr of the study are shown in white.

Materials and Methods

Study Area. The study was conducted in northern and central Illinois from 1998 to 2003 (Fig. 1). Most of the state is intensively farmed for corn, *Zea mays* L., and soybean, *Glycine max* (L.) Merr., production, creating extreme annual vegetative variation in the landscape. After the fall harvest, areas of high biomass and shaded cover for white-tailed deer are drastically transformed into fallow fields with no refugia. Another result of the intense agricultural pressure has been the development of forests that are either small, patchy woodlots or greenbelts associated with rivers, creeks, or drainage canals.

County Deer Check Stations. We visited check stations on the first weekend of the firearm hunting season, usually the third weekend in November (20–21 November 1998; 19–20 November 1999; 17–18 November 2000; 16–17 November 2001; 22–23 November 2002; and 21–22 November 2003). During this period, adult *I. scapularis* are actively host seeking (Bouseman et al. 1990), but it is unknown whether the season coincides with peak adult *I. scapularis* activity. In Illinois, hunters are required to bring harvested deer to any county check station on the day the deer was killed. In total, 20 county check stations were visited, and we examined deer from 37 counties. The Ogle County station (in Castle Rock State Park, the first described tick focus in Illinois (Bouseman et al. 1990, Kitron et al. 1991) was visited every year. The remaining 19 check stations (Will, Kankakee, Grundy, La Salle, Bureau, Putnam, Marshall, Peoria, Woodford, Tazewell, Fulton, Mason, Schuyler, Brown, Cass, Morgan, Scott, Pike, and Calhoun) were located near the Illinois River, and although several of these stations were revisited during the study, due to occasional staff shortages we were not able to visit all stations every year.

Hunter Survey and Tick Collections. Hunters were asked when they shot their deer and whether they could approximate on a 1:150,000 scale street and topography map where the deer was harvested. Information on deer age and sex was collected and recorded. We used a deer examination technique similar to that described by Gill et al. (1993). Because the head and neck are the primary sites of tick adult tick attachment (Watson and Anderson 1976), deer were inspected from the top of the head, just rostral to the ear, posteriorly to the scapula, and from the ventral midline to the dorsal midline of the neck. Only one side of the neck was inspected. Although this technique probably decreased accuracy and sensitivity, we used this method for two reasons. First, deer inspection was carried out after the required check-in procedure, and hunters were generally anxious to leave. By prioritizing the head and neck, we kept our examination time brief. Second, we standardized the examination to reduce examiner bias and to allow spatial and temporal infestation comparisons. We set a goal of examining at least 50 deer per county check station (100, if possible), but we were not always able to reach the goal in all counties. Ticks were collected and placed live in a vial containing a slightly moistened cotton ball and kept at 4°C until further analysis. In the laboratory, ticks were identified to species, sex, and stage of development, and the data were recorded for each deer.

Spatial Analysis. County line maps (ISGS 1998) and land cover maps (Luman et al. 1996) were acquired from the Illinois Natural Resources Geospatial Data Clearinghouse. Map locations indicating where deer were shot were digitized into a geographic information system (ArcMap, ESRI, Redlands, CA) by using a street overlay for the state of Illinois (IDNR 1994). The data were projected in Universal Transverse Mercator Zone 16 N. Deer attribute data were entered into Microsoft Excel (Microsoft, Redmond, WA) and then joined with the location data in ArcMap.

Data Analysis. Deer data were grouped by harvest counties and by year. Prevalence (proportion of infested deer) and intensity (number of ticks per infested deer) were calculated for *I. scapularis, D. albipictus,* and coinfestation with both tick species. *I. scapularis* density (number of ticks per deer) by sex and the average proportion of male ticks among *I. scapularis* infested deer were calculated.

Kruskal–Wallis (KW) H test (SPSS Inc. 2004), the nonparametric analog of one-way analysis of variance (ANOVA) was used to examine for differences in *I. scapularis* and *D. albipictus* prevalence and intensity. Nonparametric analyses contrasting infestation measures between bucks and other deer used Mann–Whitney *U*-test (MW) (SPSS Inc. 2004). Multiple comparison testing of proportions using a procedure based on a modified Dunnett's test (Zar 1999) was used to contrast Ogle County *I. scapularis* prevalence to other county prevalence measures. Linear trends in prevalence were analyzed using the Armitage method for linear trends among proportions (Zar 1999).

The expected proportion of deer coinfested by *I. scapularis* and *D. albipictus* was derived from the product of both prevalence measures (French et al. 1992). The binomial test (SPSS Inc. 2004) was used to compare the overall expected and observed prevalences, and the Wilcoxon signed rank (WSR) test (SPSS Inc. 2004) was used to compare annual observed prevalence to the expected measure between bucks and does and fawns. The WSR test was also used to compare *I. scapularis* intensity to *D. albipictus* intensity and to compare male *I. scapularis* density to female *I. scapularis* density.

Because of small sample size random effects, we used a conservative approach whereby annual comparative analyses between harvest counties were only conducted for counties where 30 or more deer were examined.

Results

Deer. From 1998 to 2003, we inspected 4,935 hunter-killed deer in the study area. Deer sex was recorded for 3,805 deer, and a 2:1 ratio of males to females (2,545 males to 1,260 females) was observed. Deer age was recorded for 4,659 deer, of which 3,958 were adults compared with 701 fawns. Both age and sex of 3,701 deer were recorded during the study. The proportion of fawns within each sex was comparable; 15.8% of females and 14.8% of males. Within each age group, the proportion of males was similar: 66.9% of adults and 65.2% of fawns.

Tick Infestation. We identified 4,066 *I. scapularis* adults and 6,530 *D. albipictus* larvae, nymphs, and adults. More than 35% of deer were infested with at least one tick; 17.1% with *I. scapularis*, 23.0% with *D. albipictus*, and 4.5% simultaneously by both tick species, slightly yet significantly greater than the expected coinfestation prevalence of 3.9% (binomial test: observed proportion, 0.955; test proportion, 0.961; $P < 0.05$). *I. scapularis* intensity was slightly less but not significantly different from *D. albipictus* intensity; 5.0 *I. scapularis* per infested deer compared with 5.8 *D. albipictus* per infested deer (WSR: $Z = -0.930$, $P = 0.1$).

In the northern portion of the study area, *I. scapularis* was the predominant tick found on deer (Fig. 2). Of the 909 ticks collected in Ogle, all but two were identified as *I. scapularis.* Similar findings were observed in Lee, Will, Kankakee, Grundy, and La Salle counties, where 741 of 746 ticks were *I. scapularis* (Fig. 2). Correspondingly, a north-to-south gradient was observed for *I. scapularis* prevalence, with the highest values in the northern part of the study area and the lowest in the southern portion (Fig. 3A).

Annual *I. scapularis* prevalence varied significantly among counties every year of the study (KW 1998: $\chi^2 = 32.7$, $P \leq 0.05$; 1999: $\chi^2 = 65.4$, $P \leq 0.05$; 2000: $\chi^2 = 77.7$, $P \leq 0.05$; 2001: $\chi^2 = 154.9$, $P \leq 0.05$; 2002: $\chi^2 =$

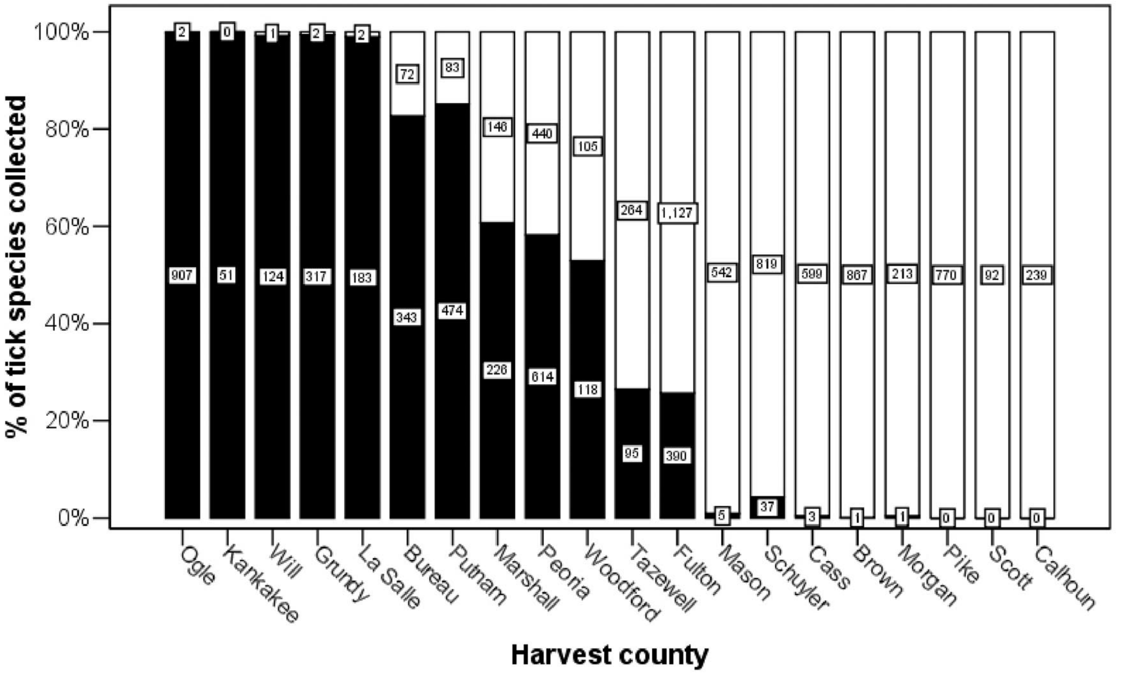

Fig. 2. Total number and relative percentage of *I. scapularis* (black portion of bar and bottom label) and *D. albipictus* (white portion and top label) collected from white-tailed deer by harvest county. Except for Ogle County, counties are arranged on the bottom axis relative to their location on the Illinois River (counties on the left are closer to the headwaters; counties on the right are nearer to the confluence with the Mississippi River).

84.3, $P \leq 0.05$; and 2003: $\chi^2 = 172.3$, $P \leq 0.05$), but intensity varied significantly only in 2001 (KW 1998: $\chi^2 = 9.0$, $P > 0.05$; 1999: $\chi^2 = 5.1$, $P > 0.05$; 2000: $\chi^2 = 14.1$, $P > 0.05$; 2001: $\chi^2 = 36.1$, $P \leq 0.05$; 2002: $\chi^2 = 20.1$, $P > 0.05$; and 2003: $\chi^2 = 15.1$, $P > 0.05$). In general, during the first 2 yr of the study, *I. scapularis* prevalence in Ogle County was significantly greater compared with counties on the Illinois River (Dunnett's multiple comparison for proportions [DMCP], 1998: Kankakee, q = 3.41, $P \leq 0.05$; Will, q = 2.75, $P \leq 0.05$; Grundy, q = 3.27, $P \leq 0.05$; La Salle, q = 4.84, $P \leq 0.05$; and 1999: Kankakee, q = 3.18, $P \leq 0.05$; Will, q = 1.41, $P > 0.05$; Putnam, q = 2.62, $P \leq 0.05$; Marshall, q = 5.22, $P \leq 0.05$; Peoria, q = 4.11, $P \leq 0.05$), but in the final 2 yr of the study, the proportion of infested deer in northern and central Illinois River counties was not significantly different from that in Ogle (DMCP, 2002: Grundy, q = −1.73, $P > 0.05$; La Salle, q = 0.162, $P > 0.05$; Bureau, q = 0.296, $P > 0.05$; Putnam, q = −1.28, $P > 0.05$; Marshall, q = −0.013, $P > 0.05$; Peoria, q = −2.32, $P > 0.05$; Tazewell, q = 1.64, $P > 0.05$; Woodford, q = −0.144, $p > 0.05$; Fulton, q = −0.190, $P > 0.05$; Schuyler, q = 2.58, $p > 0.05$; Cass, q = 3.42, $P \leq 0.05$; Brown, q = 4.99, $P \leq 0.05$; and 2003: La Salle, q = 1.64, $P > 0.05$; Putnam, q = −1.96, $P > 0.05$; Peoria, q = −0.041, $P > 0.05$; Fulton, q = −0.150, $P > 0.05$; Schuyler, q = 3.00, $P \leq 0.05$; Cass, q = 6.12, $P \leq 0.05$; Brown, q = 5.86, $P \leq 0.05$; Morgan, q = 5.58, $P \leq 0.05$; Scott, q = 5.33, $P \leq 0.05$; Pike, q = 6.23, $P \leq 0.05$).

Annual intensity demonstrated significant variation in Bureau (KW: $\chi^2 = 7.8$, $P \leq 0.05$), Peoria (KW: $\chi^2 = 13.1$, $P \leq 0.05$), and Fulton (KW: $\chi^2 = 7.7$, $P \leq 0.05$). Peak intensity levels occurred in the first two counties in 2001, but intensity in Fulton County peaked in 2003 (Fig. 4A). Significant variation in annual prevalence was observed in seven counties: Ogle (KW: $\chi^2 = 12.2$, $P \leq 0.05$), Kankakee (KW: $\chi^2 = 8.3$, $P \leq 0.05$), Putnam (KW: $\chi^2 = 24.0$, $P \leq 0.05$), Marshall (KW: $\chi^2 = 22.1$, $P \leq 0.05$), Peoria (KW: $\chi^2 = 26.4$, $P \leq 0.05$), Woodford (KW: $\chi^2 = 4.2$, $P \leq 0.05$), and Fulton (KW: $\chi^2 = 8.0$, $P \leq 0.05$). A significant increasing linear trend in annual prevalence was observed in Fulton County (Armitage method for linear trends among proportions: $\chi^2 = 8.03$, $P < 0.05$; χ^2 for linear trend = 7. 8, $P < 0.01$; and χ^2 for departure from linear trend = 0.21, $P > 0.5$).

Almost one-quarter of bucks were infested with *I. scapularis*, significantly greater than the 7% infestation rate observed for does and fawns (MW: Z = 13.7, $P \leq 0.05$). Intensity and prevalence were greater for bucks in most counties where *I. scapularis*-infested deer were found, and in several cases, significant annual and overall differences were observed (MW: Bucks versus does and fawns: all years combined: prevalence: Ogle Z = 4.33, Grundy Z = 1.99, La Salle Z = 2.60, Bureau Z = 6.306, Putnam Z = 6.75, Marshall Z = 4.92, Peoria Z = 6.53, Woodford Z = 2.38, Tazewell Z = 2.58, and Fulton Z = 5.24; $P \leq 0.05$; and intensity: Ogle Z = 3.40, La Salle Z = 2.35, and Putnam Z = 3.95, Peoria Z = 3.29, Fulton Z = 2.25; $P \leq 0.05$). In addition, compared with infested does and fawns, *I. scapularis*-infested bucks were found further south.

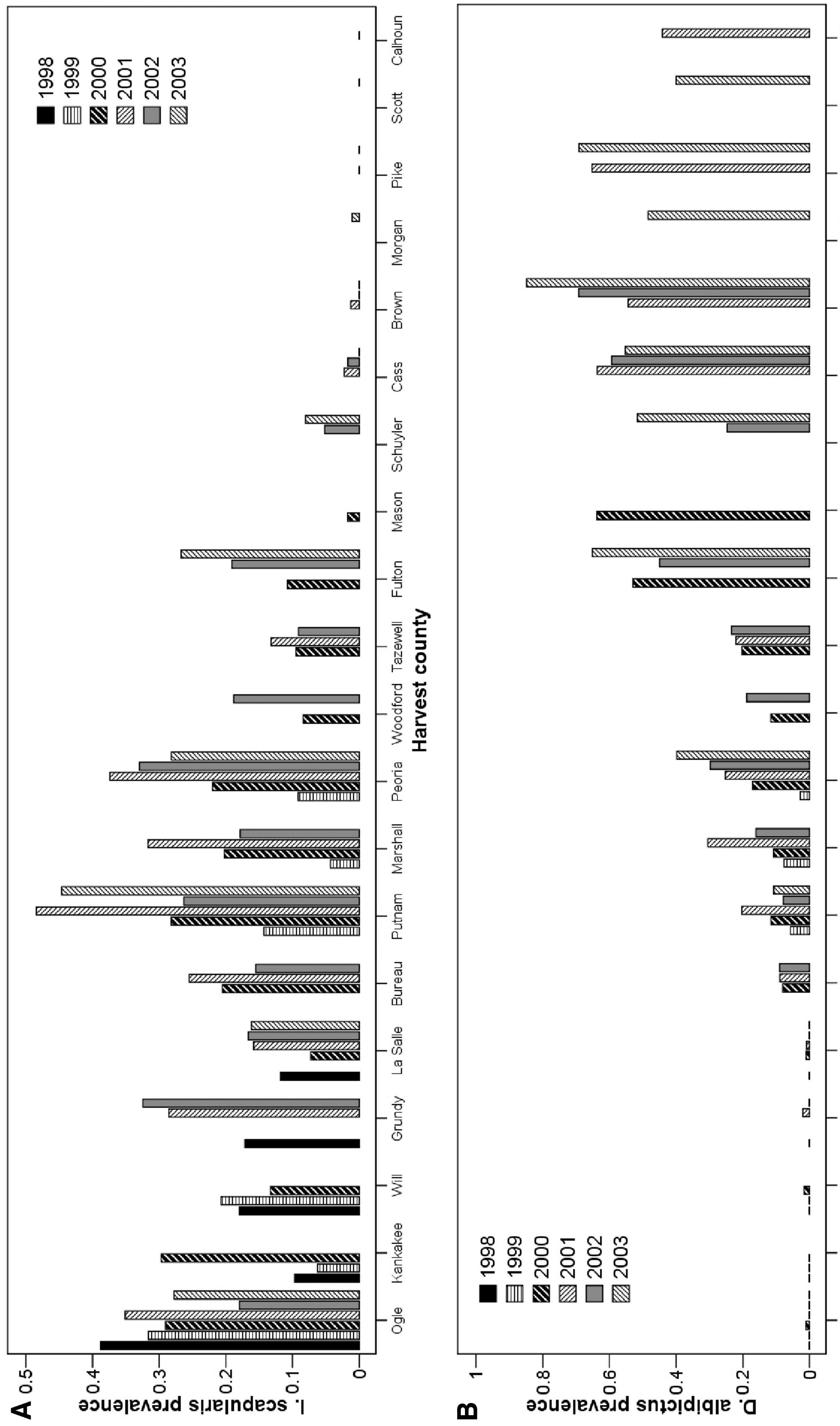

Fig. 3. (A and B) Mean annual prevalence (percentage of infested deer per deer examined) of *I. scapularis* (A) and *D. albipictus* (B) by harvest county. Only data for years when 30 or more deer were examined are shown on the figures.

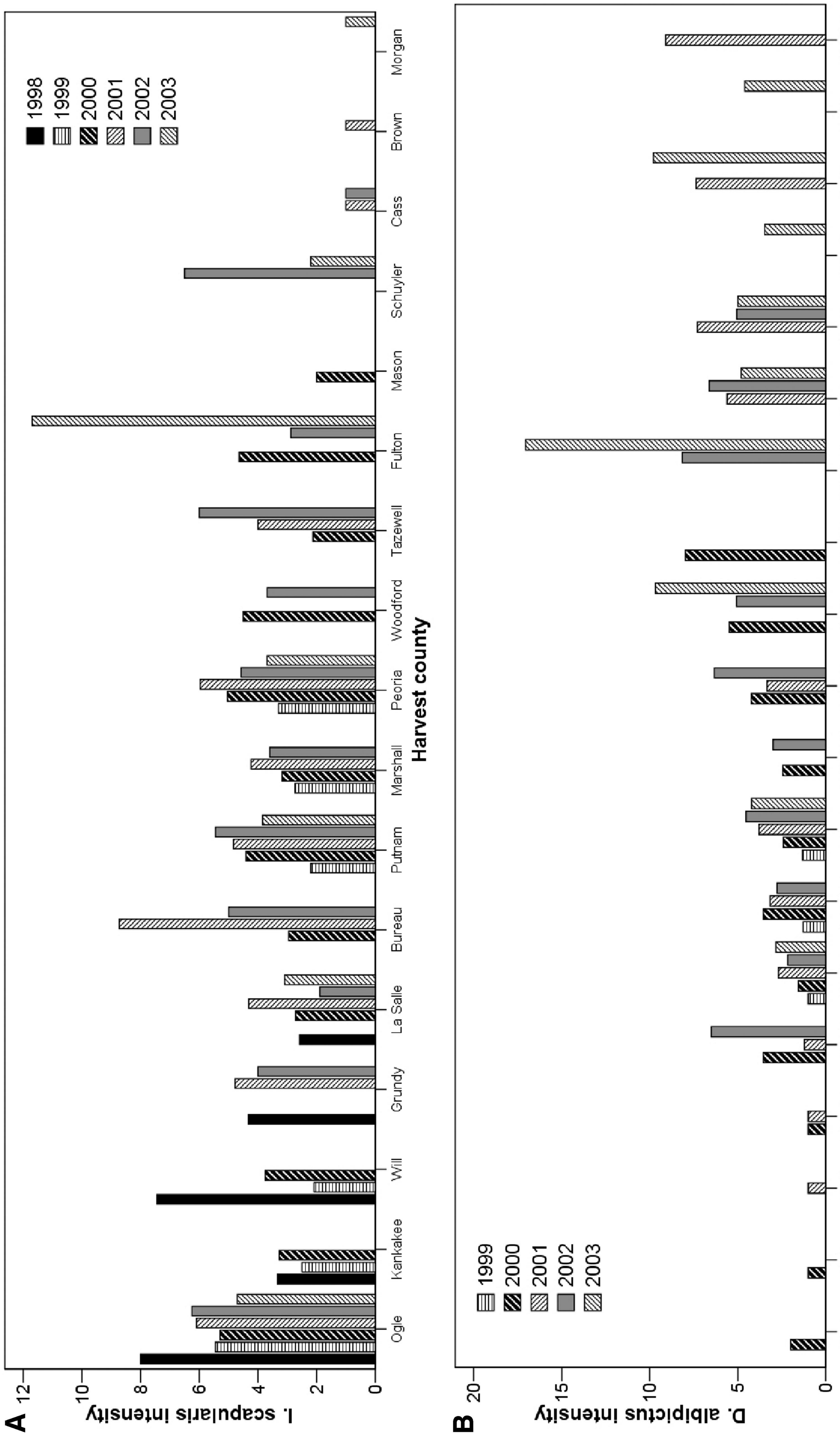

Fig. 4. (A and B) Mean annual intensity (number of ticks per infested deer) of *I. scapularis* (A) and *D. albipictus* (B) by harvest county. Data for years when <30 deer were examined are not shown.

I. scapularis sex was determined for 3,979 *I. scapularis*, of which 2,434 were males resulting in a male-to-female sex ratio of 1.6:1. We determined the sex of 2,595 ticks collected from bucks and 256 from does and fawns. Male *I. scapularis* density was significantly greater than female *I. scapularis* density (3.6 male *I. scapularis* versus 2.0 female *I. scapularis*) on infested bucks (WSR: $Z = 11.9$, $P \leq 0.05$), but no significant difference was observed for infested does and fawns (1.2 males versus 1.3 females; WSR: $Z = 1.01$, $P > 0.05$). Male *I. scapularis* proportion, male *I. scapularis* density, and female *I. scapularis* density were all significantly greater for bucks (MW: $Z = 4.45$, $Z = 14.9$, $Z = 11.7$; $P \leq 0.05$).

As with *I. scapularis*, a geographic gradient was observed for *D. albipictus* numbers and prevalence; however, the direction of the gradient was opposite to that observed for *I. scapularis* (Figs. 2, 3B). More than 50% of the deer examined from Fulton and Mason counties south to Calhoun County were infested by at least one *D. albipictus*, whereas overall *D. albipictus* prevalence north and east of Marshall County was ≈3%. Annual *D. albipictus* prevalence varied significantly across counties (KW: $\chi^2 = 1345.7$, $P \leq 0.05$) and within several counties where at least 30 deer were examined (KW: Marshall $\chi^2 = 19.4$, Peoria $\chi^2 = 46.9$, Fulton $\chi^2 = 7.2$, Schuyler $\chi^2 = 10.7$, Brown $\chi^2 = 15.4$; $P \leq 0.05$). A significant increasing linear trend was observed in Peoria (Armitage method for linear trends among proportions: $\chi^2 = 47.0$, $P < 0.001$; χ^2 for linear trend $= 45.6$, $P < 0.001$; and χ^2 for departure from linear trend $= 1.42$, $P > 0.5$). Annual county intensities were generally greater in the lower portion of the river (Fig. 4B), and overall *D. albipictus* intensity was highest in Schuyler, Calhoun, and Pike counties.

As was observed with *I. scapularis* infestation, *D. albipictus* prevalence and intensity were significantly higher for bucks. Prevalence was 39.3% for bucks and 9.3% for does and fawns (MW: $Z = 20.7$, $P \leq 0.05$), whereas intensity was 6.8 for bucks and 2.2 for does and fawns (MW: $Z = 11.3$, $P \leq 0.05$). Moreover, in the northern counties where only a few *D. albipictus* were found during the course of the study, they were found exclusively on bucks.

Coinfestation prevalence was usually greater than expected where both species were found, although significance was more likely in the central portion of the study area (Table 1). Buck coinfestation was the basis for these findings, because bucks were significantly more likely to be coinfested (8.3% compared with 0.6% for does and fawns; MW: $Z = 10.2$, $P \leq 0.05$).

Table 1. Within-harvest county comparisons of observed and expected coinfestation prevalence

County	Observed prevalence	Expected prevalence	*P* value[a]
Ogle	0.002	0.001	NS[b]
Kankakee	0	0	—
Will	0	0.001	NS
Grundy	0.006	0.002	NS
La Salle	0.002	0.001	NS
Bureau	0.069	0.018	<0.0001
Putnam	0.078	0.035	<0.001
Marshall	0.076	0.029	<0.0001
Peoria	0.117	0.058	<0.0001
Woodford	0.050	0.020	<0.05
Tazewell	0.048	0.023	<0.05
Fulton	0.148	0.100	<0.01
Mason	0	0.011	NS
Schuyler	0.058	0.024	<0.05
Cass	0.011	0.007	NS
Brown	0.004	0.003	NS
Morgan	0.011	0.005	NS
Pike	0	0	
Scott	0	0	
Calhoun	0	0	

[a] Binomial test.
[b] Not significant; $P > 0.05$.

Discussion

In 1986, an epizootic of bovine anaplasmosis (*A. caudatum*) occurred in an Adams County ranch, likely due to the introduction of infected cattle from Fulton County (Smith et al. 1989). *D. albipictus* was excluded as a vector, because it had not been found in the areas where the outbreak either originated or occurred, although foci were known in southern Illinois (Smith et al. 1989). The next year, *I. scapularis*-infested deer were first found in northwestern Illinois (Jo Daviess County), and no infested deer were reported from three counties near the Illinois River (Kankakee, Livingston, and Schuyler). A broader survey in 1988 yielded 27.1 and 37.5% prevalence in Ogle and Rock Island counties, respectively. Near the Illinois River, a single deer of 53 was infested in Knox County, and one *I. scapularis* was recovered from one of eight deer examined in Putnam County (Bouseman et al. 1990). Deer inspections in other Illinois River counties yielded no *I. scapularis* (Will, Kendall, Grundy, La Salle, Marshall, Woodford, Tazewell, Mason, Schuyler, Cass, Adams, and Pike) (Bouseman et al. 1990).

Our results are consistent with the historical geographical pattern of both species—deer infestation was greatest with *I. scapularis* in the north and with *D. albipictus* in the south. Both species' geographic ranges expanded and overlapped along the Illinois River; *Ixodes scapularis*-infested deer were found in all but two of the 1988 deer survey counties (Adams and Pike), and winter ticks were discovered in counties near the 1986 epizootic (Fulton, McDonough, Adams, Schuyler, and Brown). Furthermore, annual *I. scapularis* prevalence in several Illinois River counties was significantly higher than in Ogle County, which historically has had the highest *I. scapularis* tick activity in the state.

Compared with several sites in Wisconsin (French 1995, Riehle and Paskewitz 1996) and Minnesota (Gill et al. 1993), *I. scapularis* prevalence and intensity were lower in our study area. A possible explanation may lie in the quality and availability of tick habitat in the area. An *I. scapularis* habitat suitability model developed using Wisconsin and northern Illinois tick, vegetation, and environmental data (Guerra et al. 2002) demonstrated that *I. scapularis* presence was more probable in areas with deciduous forests, fertile soils (e.g., alfisols), sandy soil texture, and sedimentary bedrock, whereas grasslands, coniferous forests, acidic soils (e.g., spodosols), clay soil texture, and Precambrian bedrock were negatively associated with tick presence. When we applied the model to central Illinois, most deciduous forests paralleling the Illinois River were less suitable to their northern counterparts due to clay soils and Precambrian bedrock substrate (M.R.C., unpublished data).

Another possibility for the low infestation numbers may be that the deer surveys occurred after peak autumnal *I. scapularis* activity, as suggested by the male-to-female tick ratio. Because female ticks drop off after mating and feeding, but male ticks remain on the host for further copulations (Oliver 1989, Yuval et al. 1990), as the number of questing adults decreases, the ratio of males to females on the host increases (Main et al. 1981). Our ratio of 1.6 males to one female tick was similar to that reported by Yuval and Spielman (1990) (1.7M:1F) and by Kitron et al. (1991) (1.6M: 1F), and the actual ratio was likely greater because male ticks are more easily overlooked than females. Finally, because our examinations were limited, prevalence and intensity were underestimated.

A consequence of low *I. scapularis* intensities is that significant variation among and within counties was not readily observed. However, intensity varied significantly across the study area in 2001, when temperatures were remarkably warmer than normal (record warmest November in Illinois; average November temperature across the study area was 5°C above normal NCDC 2002a,b). Intensity was also significantly higher in 2001 for Peoria and Bureau counties. Warmer temperatures may have increased questing tick activity and deer–tick encounters (Daniels et al. 1989, Mount et al. 1997), resulting in higher and more variable intensities. In Fulton County, annual intensity was significantly greater in 2003, and a significant increasing linear trend in annual prevalence was observed. Although average temperature in the study area was slightly higher than normal in November 2003 (NCDC 2003), these data suggest that *I. scapularis* population in Fulton increased during the course of the study.

The observation that bucks were significantly more infested by both tick species was in agreement with previous studies (Main et al. 1981, French et al. 1992, Kitron et al. 1992, Amerasinghe et al. 1993, Kollars et al. 1997). In addition, infested bucks were more widespread across the study area. At the margins of their distributions, *I. scapularis* and *D. albipictus* were recovered exclusively from bucks. It has been postulated that bucks are more heavily infested during the breeding season because they are more mobile within their home ranges, compared with does and fawns, thereby increasing their likelihood of acquiring ticks (Main et al. 1981). Another possibility may be sex-based differences in grooming behaviors, because males of several ungulate species denote less time to self-grooming during the breeding season, resulting in higher tick densities (Hart and Hart 1992, Mooring and Hart 1995, Mooring et al. 1996). Regardless of the reason for their greater infestation, bucks may be sensitive indicators of low-density tick populations and important long-distance dispersal hosts.

Based on previous investigations and our current findings, we speculate that the primary source of blacklegged ticks was the Rock River corridor and ultimately, Wisconsin. Southerly expansion of the geographic distribution, compared with easterly establishment, was more efficient in Wisconsin (Riehle and Paskewitz 1996), and in Illinois where the tick was first found in northwestern and north central counties (Bouseman et al. 1990). Ticks in the extreme northeastern portion of the Illinois River may have originated from a focus in northwestern Indiana (Pinger and Glancy 1989), but infested deer were first demonstrated on the Illinois River in Putnam County (Bouseman et al. 1990), the closest point between the Illinois and Rock rivers (Fig. 1). Putnam and nearby counties also had some of the highest *I. scapularis* prevalence and intensity measurements, perhaps a partial outcome of long-established tick populations. Our findings demonstrate that *I. scapularis* as well as *D. albipictus* continue to expand their geographic range in the north central United States. We anticipate that population genetic studies using polymorphic genetic markers will shed some light on the geographic origin of *I. scapularis* in Illinois and in the region.

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References Cited

Amerasinghe, F. P., N. L. Breisch, K. Neidhart, B. Pagac, and T. W. Scott. 1993. Increasing density and *Borrelia burgdorferi* infection of deer-infesting *Ixodes dammini* (Acari: Ixodidae) in Maryland. J. Med. Entomol. 30: 858–864.

Bouseman, J. K., U. Kitron, C. E. Kirkpatrick, J. Siegel, and K. S. Todd. 1990. The status of *Ixodes dammini* (Acari: Ixodidae) in Illinois. J. Med. Entomol. 27: 556–560.

Cortinas, M. R., M. A. Guerra, C. J. Jones, and U. Kitron. 2002. Detection, characterization, and prediction of tick-borne disease foci. Intl. J. Med. Microbiol. 291: 11–20.

Daniels, T. J., D. Fish, and R. C. Falco. 1989. Seasonal activity and survival of adult *Ixodes dammini* (Acari: Ixodidae) in southern New York state. J. Med. Entomol. 26: 610–614.

Daniels, T. J., D. Fish, and I. Schwartz. 1993. Reduced abundance of *Ixodes scapularis* (Acari: Ixodidae) and Lyme disease risk by deer exclosure. J. Med. Entomol. 30: 1043–1049.

Deblinger, R. D., M. L. Wilson, D. W. Rimmer, and A. Spielman. 1993. Reduced abundance of immature *Ixodes dammini* (Acari: Ixodidae) following incremental removal of deer. J. Med. Entomol. 30: 144–150.

Demarais, S., H. A. Jacobson, and D. C. Guynn. 1987. Effects of season and area on ectoparasites of white-tailed deer (*Odocoileus virginianus*) in Mississippi. J. Wildl. Dis. 23: 261–266.

Drew, M. L., K. Loken, R. F. Bey, and R. D. Swiggum. 1988. Ixodes dammini: occurrence and prevalence of infection with *Borrelia* spp. in Minnesota. J. Wildl. Dis. 29: 64–72.

French, J. B. 1995. *Ixodes scapularis* (Acari: Ixodidae) at the edge of its range in southern Wisconsin. J. Med. Entomol. 32: 876–881.

French, J. B., W. L. Schell, J. J. Kazmierczak, and J. P. Davis. 1992. Changes in population density and distribution of *Ixodes dammini* (Acari: Ixodidae) in Wisconsin during the 1980s. J. Med. Entomol. 29: 723–728.

Gill, J. S., R. C. Johnson, M. K. Sinclair, and A. R. Weisbrod. 1993. Prevalence of the Lyme disease spirochete, Borrelia burgdorferi, in deer ticks (*Ixodes dammini*) collected from white-tailed deer (*Odocoileus virginianus*) in Saint Croix State Park, Minnesota. J. Wildl. Dis. 29: 64–72.

Godsey, M. S., Jr., T. E. Amundson, E. C. Burgess, W. Schell, J. P. Davis, R. Kaslow, and R. Edelman. 1987. Lyme disease ecology in Wisconsin: distribution and host preferences of *Ixodes dammini* and prevalence of antibody to *Borrelia burgdorferi* in small mammals. Am. J. Trop. Med. Hyg. 37: 180–187.

Guerra, M. A. 2000. Predicting the risk of lyme disease in the midwestern United States: surveillance methods, environmental determinants, and geographic distribution. Ph.D. dissertation. University of Illinois, Urbana, IL.

Guerra, M. A., E. Walker, C. Jones, S. Paskewitz, M. R. Cortinas, A. Stancil, L. Beck, M. Bobo, and U. Kitron. 2002. Predicting the risk of Lyme disease: habitat suitability for *Ixodes scapularis* in the north-central U.S. Emerg. Infect. Dis. 8: 289–297.

Hart, B. L., and L. A. Hart. 1992. Reciprocal allogrooming in impala, *Aepyceros melampus.* Anim. Behav. 44: 1073–1083.

[ISGS] Illinois State Geological Survey. 1998. Illinois county boundaries: ISGS GIS database coverage counties. Illinois State Geological Survey, Champaign, IL.

Jackson, J. O., and G. R. DeFoliart. 1970. *Ixodes scapularis* Say in northern Wisconsin. J. Med. Entomol. 7: 124–125.

Kitron, U., C. J. Jones, and J. K. Bouseman. 1991. Spatial and temporal dispersion of immature *Ixodes dammini* (Acari: Ixodidae) on *Peromyscus leucopus* in northwestern Illinois. J. Parasitol. 77: 945–949.

Kitron, U., C. J. Jones, J. K. Bouseman, J. A. Nelson, and D. L. Baumgartner. 1992. Spatial analysis of the distribution of *Ixodes dammini* (Acari: Ixodidae) on white-tailed deer in Ogle County, Illinois. J. Med. Entomol. 29: 259–266.

Kollars, T. M., Jr., L. A. Durden, E. J. Masters, and J. H. Oliver, Jr. 1997. Some factors affecting infestation of white-tailed deer by blacklegged ticks and winter ticks (Acari: Ixodidae) in southeastern Missouri. J. Med. Entomol. 34: 372–375.

Kollars , T. M., Jr., J. H. Oliver, Jr., E. J. Masters, P. G. Kollars, and L. A. Durden. 2000. Host utilization and seasonal occurrence of *Dermacentor.* Exp. Appl. Acarol. 24: 631–643.

Luman, D., M. Joselyn, and L. Suloway. 1996. Critical trends assessment - land cover database of Illinois, 1991–1995. Geographic Information Systems Database, Illinois Department of Natural Resources, Champaign, IL.

Main, A. J., H. E. Sprance, K. O. Kloter, and S. E. Brown. 1981. Ixodes dammini (Acari: Ixodidae) on white-tailed deer *Odocoileus virginianus* in Connecticut, USA. J. Med. Entomol. 18: 487–492.

Mooring, M. S., and B. L. Hart. 1995. Differential grooming rate and tick load of territorial male and female impala, *Aepyceros melampus.* Behav. Ecol. 6: 94–101.

Mooring, M. S., A. A. McKenzie, and B. L. Hart. 1996. Role of sex and breeding status in grooming and total tick load of impala. Behav. Ecol. Sociobiol. 39: 259–266.

Mount, G. A., D. G. Haile, and E. Daniels. 1997. Simulation of blacklegged tick (Acari: Ixodidae) population dynamics and transmission of *Borrelia burgdorferi.* J. Med. Entomol. 34: 461–484.

[NCDC] National Climatic Data Center/NESDIS/NOAA. 2002a. Climatography of the United States No. 81. Monthly station normals of temperature, precipitation, and heating and cooling degree days 1971–2000, 11–Illinois. Asheville, NC.

[NCDC] National Climatic Data Center/NESDIS/NOAA. 2002b. The climate of 2001.(U.S. and global climate perspectives). Asheville, NC. (http://www.ncdc.noaa.gov/oa/climate/research/2001/perspectives.html).

[NCDC] National Climatic Data Center/NESDIS/NOAA. 2003. Climate of 2003 - November in historical perspective. Asheville, NC. (http://www.ncdc.noaa.gov/oa/climate/research/2003/nov/nov03.html).

Nixon, C. M., L. P. Hansen, P. A. Brewer, and J. E. Chelsvig. 1991. Ecology of white-tailed deer in an intensively farmed region of Illinois. Wildl. Monogr. 118.

Oliver, J. H., Jr. 1989. Biology and systematics of ticks (Acari: Ixodida). Annu. Rev. Biol. Syst. 20: 397–430.

Piesman, J. 2002. Ecology of *Borrelia burgdorferi* sensu lato in North America, pp. 223–249. *In* J. Gray, O. Kahl, R. S. Lane, and G. Stanek [eds.], Lyme borreliosis: biology, epidemiology and control. CABI Publishing, Oxon, United Kingdom.

Piesman, J., A. Spielman, P. Etkind, T. K. Ruebush, II, and D. D. Juranek. 1979. Role of deer in the epizootiology of *Babesia microti* in Massachusetts, U.S.A. J. Med. Entomol. 15: 537–540.

Pinger, R. R., and T. Glancy. 1989. Ixodes dammini (Acari: Ixodidae) in Indiana. J. Med. Entomol. 26: 130–131.

Rand, P. W., C. Lubelczyk, G. R. Lavigne, S. Elias, M. S. Holman, E. H. Lacombe, and R. P. Smith. 2003. Deer density and abundance of *Ixodes scapularis* (Acari: Ixodidae). J. Med. Entomol. 40: 179–184.

Riehle, M., and S. M. Paskewitz. 1996. Ixodes scapularis (Acari: Ixodidae): status and changes in prevalence and distribution in Wisconsin between 1981 and 1994 measured by deer surveillance. J. Med. Entomol. 33: 933–938.

Samuel, W. M., and D. A. Welch. 1991. Winter ticks on moose and other ungulates: factors influencing their population size. Alces 27: 169–182.

Smith, R. D., L. L. Hungerford, and C. T. Armstrong. 1989. Epidemiologic investigation and control of an epizootic of anaplasmosis in cattle in winter. J. Am. Vet. Med. Assoc. 195: 476–480.

SPSS Inc. 2004. SPSS for Windows 12.0.2. SPSS Inc., Chicago, IL.

Spielman, A. 1988. Lyme disease and human babesiosis: evidence incriminating vector and reservoir hosts, pp. 147–165. *In* P. T. England and A. Scher [eds.], The biology of parasitism. Wiley, New York.

Stafford, K. C. 1993. Reduced abundance of *Ixodes scapularis* (Acari: Ixodidae) with exclusion of deer by electric fencing. J. Med. Entomol. 30: 986–996.

Watson, T. G., and R. C. Anderson. 1976. *Ixodes scapularis* Say on white-tailed deer (*Odocoileus virginianus*) from Long Point, Ontario. J. Wildl. Dis. 12: 66–71.

Weisbrod, A. R., and R. C. Johnson. 1989. Lyme disease and migrating birds in the Saint Croix River Valley. Appl. Environ. Microbiol. 55: 1921–1924.

Welch, D. A., W. M. Samuel, and C. J. Wilke. 1991. Suitability of moose, elk, mule deer, and white-tailed deer as hosts for winter ticks (*Dermacentor albipictus*). Can. J. Zool. 69: 2300–2305.

Wilson, M. L., G. H. Adler, and A. Spielman. 1985. Correlation between abundance of deer and that of the deer tick, *Ixodes dammini* (Acari: Ixodidae). Ann. Entomol. Soc. Am. 78: 172–176.

Wilson, M. L., S. R. Telford, III, J. Piesman, and A. Spielman. 1988. Reduced abundance of immature *Ixodes dammini* (Acari: Ixodidae) following elimination of deer. J. Med. Entomol. 25: 224–228.

Wilson, M. L., A. M. Ducey, T. S. Litwin, T. A. Gavin, and A. Spielman. 1990. Microgeographic distribution of immature *Ixodes dammini* ticks correlated with that of deer. Med. Vet. Entomol. 4: 151–159.

Yuval, B., R. D. Deblinger, and A. Spielman. 1990. Mating behavior of male deer ticks *Ixodes dammini* (Acari: Ixodidae). J. Insect Behav. 3: 765–772.

Zar, J. H. 1999. Biostatistical analysis, 4th ed. Prentice-Hall, Upper Saddle River, NJ.

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