Lyme Disease in California: Ecology and Epidemiology

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ABSTRACT: Lyme disease (LD), caused by the spirochete *Borrelia burgdorferi* (Bb), is the most commonly reported vector-borne disease in the United States. We have been studying the ecology, epidemiology, and prevention of LD since 1982. The primary objectives of this research are intended to clarify the transmission cycles of Bb and closely related spirochetes in diverse habitats; to determine what behaviors and environmental factors elevate the risk of human exposure to Bb-infected ticks; and to evaluate preventive methods. Several genospecies of LD spirochetes are maintained in transmission cycles involving western gray squirrels, dusky-footed wood rats, California kangaroo rats or deer mice, and three species of *Ixodes* ticks. The western gray squirrel has been implicated as a primary reservoir host of Bb in dense woodlands. The western black-legged tick, *Ixodes pacificus*, especially the nymphal stage, is the primary bridging vector from wildlife reservoirs to people. In Mendocino County, the prevalence of spirochete-infection in the nymphs typically averages between 5 and 10% (range, <1% to 41% among individual sites) in various subtypes of dense woodlands. Some activities that were found to contribute significantly to risk of exposure to LD or host-seeking *I. pacificus* ticks included cutting wood, and contact with either low vegetation bordering the uphill margins of hillside-hiking trails or leaf-litter areas and wood in dense woodlands. To determine how people might become infested with *I. pacificus* nymphs, six behaviors were evaluated as potential risk factors for encountering the nymphs in a hardwood forest. Activities entailing considerable contact with wood (e.g., sitting on logs or against tree trunks) resulted in greater infestation by nymphs than behaviors involving exposure solely to leaf litter. The ultimate goal of this long-term research is to use the basic knowledge gleaned to develop and implement strategies for reducing human exposure to LD and other tick-borne agents.

KEY WORDS: *Borrelia burgdorferi*, *Ixodes pacificus*, Lyme disease, prevention, risk factor, rodents, *Sciurus griseus*, spirochete, tick, western gray squirrel

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Lyme disease (LD), caused by the spirochete *Borrelia burgdorferi* (Bb), is the most commonly reported vector-borne disease in the United States. Spirochetes are spiral-shaped bacteria, and those belonging to the genus *Borrelia* are transmitted by arthropods, especially ticks. In California, at least 9 different disease agents are transmitted to humans or other animals by ticks (1 virus, 7 bacteria, 1 protozoan), but Bb causes more recognized cases of clinical disease than do the others with approximately 100 human cases of LD reported annually to state health authorities. Most cases are contracted in northern counties, especially in the northwestern region where the annual incidence per 100,000 population reached 65.7 cases in southern Humboldt County during the early 1990s (Ley *et al*. 1994). The number of cases reported is apt to increase in the foreseeable future, because in 2005, LD became a laboratory-reportable disease in California for the first time.

We have been studying the ecology, epidemiology, and prevention of LD since 1982. The primary objectives of this research are intended to clarify the transmission cycles of Bb and closely related spirochetes in diverse habitats; to determine what behaviors and environmental factors elevate the risk of human exposure to Bb-infected ticks; to investigate the genetic biodiversity of LD-group spirochetes, Bb sensu lato (s.l.); and to evaluate preventive methods for reducing exposure to vector ticks. The purpose of this brief communication is to review some of the ecological and epidemiological findings, as well as preventive measures, that may be of interest to individuals who work or recreate in tick-infested habitats in the Far West.

In northwestern California, several genospecies of Bb s.l. were found to be maintained in transmission cycles involving western gray squirrels (*Sciurus griseus*), dusky-footed wood rats (*Neotoma fuscipes*), California kangaroo rats (*Dipodomys californicus*), or deer mice (*Peromyscus maniculatus*), and 3 species of *Ixodes* ticks. The western black-legged tick *I. pacificus*, a vicious human-biter having catholic feeding habits, is the primary bridging vector of Bb from wildlife to people (Burgdorfer *et al*. 1985, Lane and Lavoie 1988, Clover and Lane 1995), whereas the normally non-human biting ticks *I. spinipalpis* and *I. jellisoni* transmit *B. bissettii* or uncharacterized *Borrelia* spp. predominately to rodents. The transmission cycle for each LD spirochete appears to be largely host-driven and therefore habitat-dependent. For example, intense foci of Bb infection are found in dense woodlands hosting western gray squirrels and *I. pacificus* ticks (e.g., Clover and Lane 1995; Tälleklint-Eisen and Lane 1999; Eisen *et al*. 2003; 2004*a*,*b*; Lane *et al*. 2005); in contrast, certain uncharacterized genotypes of Bb s.l. circulate in grasslands supporting populations of California kangaroo rats and *I. jellisoni* ticks (Lane *et al*. 1999).

Some behavioral factors that contribute significantly to risk of exposure to LD or *I. pacificus* ticks include time spent outdoors in the fall multiplied by a clothing index and woodcutting (Lane *et al*. 1992), the use of wide maintained trails for more than 5 hours per week (Ley *et al*. 1995), and contact with low vegetation bordering the uphill margins of hillside-hiking trails (Kramer and Beesley 1993, Clover and Lane 1995, Lane 1996) or leaf-litter areas and wood in dense woodlands (Lane *et al*.

2004). The tiny (1.0-1.2 mm long), inconspicuous nymph of *I. pacificus*, like that of its eastern North American counterpart *Ixodes scapularis*, appears to transmit Bb infection to humans more often than the larger, more easily detected adult ticks (Clover and Lane 1995). The prevalence of Bb s.l. infection in *I. pacificus* nymphs averages between ≈5 and 10%, with a range from <1 to 41%, among individual sites in dense woodlands in Mendocino County (e.g., Clover and Lane 1995, Tällenklint-Eisen and Lane 1999, Eisen *et al*. 2003). Furthermore, the infection prevalence in *I. pacificus* nymphs normally is several times higher than it is in adults from the same population of ticks (Clover and Lane 1995, Eisen *et al*. 2004*c*).

To determine how people might become infested with *I. pacificus* nymphs, six behaviors were evaluated as potential risk factors for acquiring this life stage in a hardwood forest (Lane *et al*. 2004). Behaviors involving considerable contact with wood resulted in significantly greater infestation by nymphs than activities involving exposure solely to leaf litter. Time-adjusted tick-acquisition rates demonstrated that sitting on logs was by far the riskiest behavior; indeed, subjects acquired, on average, 7 nymphs per hour while sitting atop logs. The number of ticks acquired while walking was similar irrespective of the type of footwear worn (i.e., hiking boots, hiking sandals, or running shoes).

To learn how *B. burgdorferi* is maintained and disseminated in woodlands, ≈50 species of birds and small mammals were evaluated as potential hosts of Bb s.l. and vector ticks in 2002 and 2003 (Eisen *et al*. 2004*a*,*b*; Lane *et al*. 2005). Only one vertebrate, the western gray squirrel, fulfilled the criteria that would define a primary reservoir host. This sciurid rodent was infested abundantly with *I. pacificus* subadults, (larvae and nymphs), a high percentage (80%) of the squirrels sampled was infected with Bb, and 47% of the *I. pacificus* larvae that had attached to squirrels were infected with LD spirochetes. Also, the geographical distribution of this rodent in California mirrors that of most reported human cases of LD. The western gray squirrel is a game species in California, and since ≈60,000 to 70,000 "tree" squirrels are harvested annually (Tom Blankinship, Calif. Dept. of Fish and Game, pers. commun., 2004), it is recommended that hunters consider wearing protective gloves (e.g., disposable latex gloves) while field-dressing tree squirrels as a precautionary measure to avoid exposure to potentially infected bodily fluids or tissues.

The ultimate goal of this research is to use the basic knowledge gleaned during these long-term studies to develop and implement strategies for reducing human exposure to LD and other tick-borne agents. Contraction of tick-borne diseases generally may be prevented by educational campaigns, the use of personal protection measures (e.g., application of acaricides or repellents to clothing or skin; frequent self-inspections), avoidance of risky behaviors (e.g., sitting on logs in dense woodlands) and prompt removal of embedded ticks. No human vaccine is available commercially for protection against LD, however.

Another method that has not been advanced in educational materials seen by the author to date, but one that offers a final line of defense against tick-borne infections, is to check one's bedding carefully for presence of engorged ticks each morning for several days after exposure to tick-infested habitats. This is particularly important for individuals who have been exposed to woodlands inhabited by *I. pacificus* nymphs. People who are bitten by *I. pacificus* or *I. scapularis* nymphs often do not detect the tick that had bit them, and fed *I. pacificus* nymphs sometimes detach from individuals who are asleep (Berger 1989, R. S. Lane unpubl. data). Ticks found attached to skin or detached in bedding can be submitted to some commercial laboratories for diagnostic testing for presence of Bb. If a tick yields a positive test-result (e.g., by polymerase chain reaction), the person could be administered an appropriate antibiotic by his or her physician on a timely basis, and a clinical case of LD may be prevented.

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