Response of nymphal *Ixodes scapularis,* the primary tick vector of Lyme disease spirochetes in North America, to barriers derived from wood products or related home and garden items

Joseph Piesman

Centers for Disease Control and Prevention, Bacterial Diseases Branch, Division of Vector-Borne Infectious Diseases, P.O. Box 2087, Ft. Collins, CO 80522, U.S.A.

Received 2 August 2006; Accepted 21 September 2006

ABSTRACT: Forest products were tested to see if they functioned as a barrier to nymphal *Ixodes scapularis*. These products could potentially be used to define a border between high density and low density tick zones on residential properties in Lyme disease endemic regions of North America. Common home and garden items were also tested. Three wood products effectively acted as barriers to nymphal *I. scapularis*: Alaska Yellow Cedar sawdust, Alaska Yellow Cedar woodchips, and cellulose. These three products were then weathered to determine how long they remained active. Cellulose and Alaska Yellow Cedar woodchips lost their activity almost immediately (within three days); in contrast, Alaska Yellow Cedar sawdust impeded crossing by nymphal ticks for up to one month. Creating barriers at the woods-lawn interface may someday play a role in integrated campaigns to prevent Lyme disease but will not serve as a stand-alone measure to block transmission of Lyme disease spirochetes. ***Journal of Vector Ecology* 31 (2): 412-417. 2006.**

Keyword Index: Lyme disease, prevention, ticks, *Ixodes scapularis*, forest products.

INTRODUCTION

Lyme disease is hyperendemic in the northeastern United States, where nymphal *Ixodes scapularis* serve as the primary vector ticks of the etiologic agent, *Borrelia burgdorferi* (Diuk-Wasser et al. 2006). Most victims of Lyme disease in the northeastern United States come into contact with infected ticks in a suburban residential setting, on their own properties (Falco and Fish 1988), during normal everyday activities such as gardening or walking the dog. An in-depth study of the landscape ecology of Lyme disease in Westchester County, NY, divided suburban properties into four habitats: woods, ecotone, ornamentals, and lawn (Maupin et al. 1991). The woods clearly contained the most ticks while lawn contained the least. Maupin et al. (1991) recommended establishing a wide artificial border (>1m) between the woods and lawn containing xeric materials such as tree bark, wood chips, pumice, or gravel to separate high human use areas from areas with high tick density. Subsequent reviews have stressed this method as part of integrated pest management (IPM) campaigns to reduce the risk of Lyme disease (Hayes and Piesman 2003, Stafford 2004).

Crude extracts derived from Alaska Yellow Cedar trees have been shown to contain acaricidal properties (Panella et al. 1997). The chemical moieties that are active against ticks include eremophilane sesquiterpenes such as nootkatone, and monoterpenes such as carvacrol (Panella et al. 2005). Moreover, chemicals derived from Alaska Yellow Cedar also act as repellents for nymphal *I. scapularis* (Dietrich et al. 2006). A border made of a forest product that possesses both acaricidal and repellent properties would not only serve to remind residents of the separation between high and low tick density zones, but may actually keep Lyme disease spirochete infected ticks from migrating from the forest to adjacent yards. The most commonly accepted and esthetically pleasing border materials used in suburban residential yards are wood chips or tree bark. Accordingly, we examined the response of nymphal *I. scapularis* to various forest products, and other related home and garden items, to determine which products might serve as a potential barrier to the movement of these ticks.

MATERIALS AND METHODS

Tick colonies

Ixodes scapularis colonies used in these experiments were derived from two sources: female ticks collected from Naval Weapons Station Earle, Monmouth County, NJ, and female ticks collected from Bridgeport, Fairfield County, CT. To maintain the colonies, larval and nymphal ticks were fed on mice and adult ticks were fed on rabbits. Between feedings, ticks were held in desiccators at saturated humidity, 22^{o} C, under a light dark 24-h cycle of 16L: 8D. All ticks used in these experiments had been in laboratory colonies for $\leq$ three generations. Flat nymphal *I. scapularis* were utilized in all test procedures; these ticks had molted to nymphs two to nine months before their selection for experiments. Test and control ticks were always selected from the same vials derived from the same animal feeding, in matched fashion.

Forest products and home and garden items

A list of the test items used in various experiments is contained in Table 1. Forest products were obtained from the Oregon State University, Department of Forest Products (Corvallis, OR). Heartwood from selected trees was milled into wood chips, mulch, or sawdust, vacuum sealed, and sent to the CDC laboratory in Ft. Collins, CO. Wood materials were stored at -20^{o} C. Chips were larger in size, averaging approximately 40 mm x 12 mm, whereas sawdust was much finer (4 mm x 1 mm); mulch contained intermediate-sized particles. The commercially available home and garden materials listed in Table 1 were purchased locally in Fort Collins, CO, or by mail order. New Jersey leaf litter materials were collected from either deciduous dominated forests or mixed deciduous-conifer forests in Monmouth County, NJ. These areas have been described previously (Schulze and Jordan 2005).

Test procedures

The experimental design took advantage of the fact that *I. scapularis* exhibits thigmotaxis and does not like to remain in exposed areas. Basically, these ticks move away from exposed, open areas and toward cover. Accordingly, nymphs were removed from the vials where they molted via the use of a fine painter's brush and placed in the middle of a 125 mm diameter filter paper (Baxter Scientific Products, McGaw Park, IL). The filter paper was set in the middle of a white enamel pan and a pencil was used to draw a 6 x 6 cm grid in the middle of the filter paper. In control runs, a total of 12 nymphs were placed into the grid and observed for 15 min. The time it took each nymph to exit the grid was recorded to the nearest minute. When calculating time to exit, nymphs not exiting were considered to have exited at 15 min, the conclusion of the observation period. For experimental trials, the test material was placed as a border around the perimeter of the grid, covering approximately 1 cm on each side of the line. Ticks were considered to have left the grid when they disappeared from sight under the test material or crawled over the test material, with all eight legs leaving the filter paper. Ticks were not allowed to crawl back into the grid area. Those attempting to return were removed from the trial to avoid confusion with those that had never exited. Matched test and control runs were performed within 15 min of each other.

Aging of test materials

Materials that elicited an avoidance response in nymphal *I. scapularis* were allowed to age in natural outdoor conditions to determine how long they maintained their activity. The test substance was placed at the lawn-woods interface in a backyard in Fort Collins (Larimer County), CO, in May of 2006. The material was exposed to wind, sun, and rain as it would be in a suburban backyard in the northeastern U.S. Although northern Colorado is much drier than Lyme disease endemic communities in the eastern U.S., the test material was placed within range of a sprinkler system that watered the vegetation for approximately 30 min, two to three times weekly.

Table 1. Source of wood products or home and garden materials tested as barriers against nymphal *Ixodes scapularis*.*

Material	Source	Location**
Alaska Yellow Cedar Sawdust	Oregon State Univ	Corvallis, OR
Alaska Yellow Cedar Woodchips	Oregon State Univ	Corvallis, OR
Cellulose	FMC Corp	Newark, DE
Incense Cedar Sawdust	Oregon State Univ	Corvallis, OR
Incense Cedar Woodchips	Oregon State Univ	Corvallis, OR
Douglas Fir Sawdust	Yard Palace	Corvallis, OR
Douglas Fir Mulch	Oregon State Univ	Corvallis, OR
Wooden Dowel	Hardwood Products	Guilford, ME
Sand	Quickrete Comp	Atlanta, GA
Filter Paper	Baxter Healthcare	McGaw Park, IL
Soil	Permagreen Organics	Arvada, CO
Gravel	Mosser Lee	Millstone, WI
New Jersey-Oak Leaves	Freehold Township	Colts Neck, NJ
New Jersey Pine Needles	Freehold Township	Colts Neck, NJ
New Jersey Mixed	Freehold Township	Colts Neck, NJ
NJ Mulch	Freehold Township	Millstone, NJ

*This article reports the results of research only. Use of product names is for identification only and is not intended to imply endorsement by the Centers for Disease Control and Prevention or any other government agency.
** Location of source or, if known, the location where materials were harvested.

RESULTS

Test materials listed in Table 1 included wood products derived from Alaska Yellow Cedar, Incense Cedar, Douglas Fir, or cellulose, as well as forest materials collected from Monmouth County, NJ. Home and garden products included wooden dowels, sand, filter paper, soil, and gravel. In matched test and control trials, the mean duration until individual nymphs exited the grid (Table 2) and the proportion of nymphs successfully exiting the grid during 15 min of observation (Table 3) were recorded. Only three wood products significantly impeded the exit of ticks from the grid: Alaska Yellow Cedar sawdust, Alaska Yellow Cedar woodchips, and cellulose. This effect was observed in both the duration until exit (Table 2) and the proportion of ticks exiting the grid (Table 3). Although Incense Cedar sawdust appeared to produce some avoidance behavior in the ticks, this effect was not significant. All other wood, garden, and household items did not impede the exit of ticks from the test grid.

In order to determine how long wood products would act as a barrier to tick movement after they had been deployed in the field, the three products that demonstrated significant activity (Alaska Yellow Cedar sawdust, Alaska Yellow Cedar woodchips, and cellulose) were allowed to age under natural conditions of exposure to sun, wind, and rain. The only measure recorded in this trial was the proportion of ticks exiting during 15 min, since the duration until exiting and the proportion exiting were closely matched during the initial trial. Before outdoor exposure, all three products significantly decreased the proportion of ticks exiting the grid (Table 4). After only three days of exposure, however, both Alaska Yellow Cedar woodchips and cellulose lost their activity. On the other hand, Alaska Yellow Cedar sawdust significantly impeded the exit of ticks from the grid for at least one month.

DISCUSSION

Suburban residents in the northeastern U.S. often live in close proximity to nymphal *I. scapularis*, and approximately 25% of these nymphs are infected with the Lyme disease spirochete, *B. burgdorferi* sensu stricto (Maupin et al. 1991). The risk of acquiring Lyme disease spirochete infection should presumably motivate people living in this habitat to use highly effective area-wide acaricides. In practice, however, many inhabitants of these communities do not use area-wide acaricides due to fears of environmental damage, toxicity, and cost (Piesman 2006). This has led a drive to present varied options for tick control to homeowners and pest management professionals as part of an Integrated Pest Management (IPM) approach to the prevention of Lyme disease (Hayes and Piesman 2003, Stafford 2004, Schulze and Jordan 2006). Landscape management has been a key part of the IPM campaign to reduce the risk of Lyme disease.

Various approaches to the manipulation of vegetation for the control of *I. scapularis* have been tried. Burning of vegetation may temporarily reduce the number of ticks present in an area, but vegetation quickly returns as do infected ticks (Mather et al. 1993, Stafford et al. 1998). Moreover, burning in highly populated areas is problematic. Mowing of vegetation (Wilson 1986) as well as leaf litter removal (Schulze et al. 1995) can decrease tick populations, but these methods are also temporary and extremely labor intensive. The use of least toxic pesticides,

Table 2. Duration (in minutes) nymphal *Ixodes scapularis* remained in grid surrounded by wood products or home and garden materials.

Material	Test[a]	Control
Alaska Yellow Cedar Sawdust	13.9 ± 3.8[b]	4.2 ± 4.1
Alaska Yellow Cedar Woodchips	11.0 ± 6.0[b]	2.6 ± 2.2
Cellulose	13.3 ± 3.9[b]	5.6 ± 4.0
Incense Cedar Sawdust	9.5 ± 6.2	4.3 ± 5.1
Incense Cedar Woodchips	2.2 ± 1.7	2.5 ± 4.0
Douglas Fir Sawdust	2.0 ± 1.4	3.4 ± 4.0
Douglas Fir Mulch	3.2 ± 3.8	1.6 ± 1.2
Wooden Dowel	8.0 ± 5.2	5.5 ± 5.5
Sand	3.5 ± 4.4	3.7 ± 5.3
Paper	2.0 ± 1.4	2.2 ± 2.3
Soil	3.0 ± 2.6	2.0 ± 1.4
Gravel	3.7 ± 4.3	3.3 ± 4.1
New Jersey Oak Leaves	2.3 ± 2.1	3.7 ± 4.1
New Jersey Pine Needles	4.2 ± 4.6	6.8 ± 4.9
New Jersey Mixed	4.7 ± 5.2	5.7 ± 6.5
New Jersey Mulch	3.7 ± 5.3	3.3 ± 4.3

[a]Mean number of minutes until exit from grid ± SD.
[b]Test significantly different from control ($P < 0.05$); Mann-Whitney test.

Table 3. Proportion of nymphal *Ixodes scapularis* failing to exit from grid surrounded by wood products or home and garden materials.

Material	Test[a]	Control
Alaska Yellow Cedar Sawdust	11/12[b]	1/12
Alaska Yellow Cedar Woodchips	8/12[b]	0/12
Cellulose	10/12[b]	1/12
Incense Cedar Sawdust	5/12	2/12
Incense Cedar Woodchips	0/12	1/12
Douglas Fir Sawdust	0/12	1/12
Douglas Fir Mulch	0/12	0/12
Wooden Dowel	2/12	2/12
Sand	1/12	2/12
Paper	0/12	0/12
Soil	0/12	0/12
Gravel	1/12	1/12
New Jersey Oak Leaves	0/12	0/12
New Jersey Pine Needles	1/12	2/12
New Jersey Mixed	2/12	3/12
New Jersey Mulch	2/12	1/12

[a]Number of nymphs failing to exit grid within 15 min/Number of nymphs tested.
[b]Test significantly different from control ($P < 0.05$); Chi-square test.

Table 4. Weathering properties of wood products and their ability to repel nymphal *Ixodes scapularis*.

Days of exposure	Material	Response[a]
0	Alaska Yellow Cedar Sawdust	12/12[b]
	Alaska Yellow Cedar Chips	8/12[b]
	Cellulose	9/12[b]
	Control	1/12
3	Alaska Yellow Cedar Sawdust	12/12[b]
	Alaska Yellow Cedar Chips	1/12
	Cellulose	4/12
	Control	2/12
7	Alaska Yellow Cedar Sawdust	10/12[b]
	Control	2/12
13	Alaska Yellow Cedar Sawdust	11/12[b]
	Control	0/12
21	Alaska Yellow Cedar Sawdust	10/12[b]
	Control	1/12
28	Alaska Yellow Cedar Sawdust	6/6[b]
	Control	1/12
35	Alaska Yellow Cedar Sawdust	2/12
	Control	2/12

[a]Number of nymphs failing to exit grid within 15 min/Number of nymphs tested.
[b]Test significantly different from control ($P < 0.05$); Chi-square test.

such as soaps or desiccants (Patrican and Allan 1995) as well as fungal agents (Zhioua et al. 1997, Benjamin et al. 2002), hold promise for inclusion in future IPM campaigns against *I. scapularis*, but these techniques require further developmental research.

The finding that suburban properties contain high populations of ticks in woodlands, and much lower populations of ticks on lawns, led to the suggestion that separating the high density tick areas from low density tick areas may reduce human-tick contact in this setting (Maupin et al. 1991). The urgency of creating this barrier on suburban properties received further emphasis from the observation that >50% of all yard area is directly adjacent to woodlands (Duffy et al. 1994), and the majority of *I. scapularis* on lawns are <1 m from the forest-lawn interface (Stafford and Magnarelli 1993). Thus, creating a distinct barrier of woodchips at the lawn-woods interface has often been incorporated into IPM campaigns against Lyme disease (Hayes and Piesman 2003, Stafford 2004). Indeed, the placement of a woodchip barrier derived from local materials around five yards in Old Lyme, CT, led to a decrease of nymphal *I. scapularis* on those lawns of 35-77% (K.C. Stafford III, personal communication). It would be interesting to see if barriers made specifically of Alaska Yellow Cedar sawdust, which prevented ticks from crossing for at least one month in our current study, would provide a greater and more consistent level of reduction of ticks on lawns.

The Alaska Yellow Cedar sawdust may have been more active than the Alaska Yellow Cedar woodchips due to the smaller particle size; this difference in particle size may allow more active volatile compounds to escape from the wood. The cellulose lost its activity immediately upon becoming damp. Cellulose might have an electrostatic charge that allows particles to cling to the ticks and discourages the ticks from crossing the barrier. This charge may be lost when the cellulose becomes damp and clumps. The prospects for using sawdust as a barrier as opposed to woodchips may be dimmed by the fact that sawdust is less aesthetically pleasing than woodchips as landscape material. This could, hopefully, be overcome by treating woodchips with active chemical moieties derived from Alaska Yellow Cedar, like nootkatone (Dietrich et al. 2006), that are highly repellent to *I. scapularis*.

The level of public health impact provided by any barrier between woods and lawn may be limited. Nymphal *I. scapularis* reportedly move <2 m (Falco and Fish 1991). It is not clear how many ticks actually move from the well-protected woods to the more exposed lawn surface. In addition, woodchip or sawdust barriers that are not repellent might actually harbor high populations of ticks themselves. Moreover, it is likely that some infected nymphs on lawns are dropped off directly as replete larvae by rodents, birds, or medium-sized mammals that enter lawns. A forest-lawn barrier would not prevent these host-derived infected nymphs from getting onto lawns. Therefore, although wood product barriers may play some limited role in reducing migration of ticks onto high-use lawns on suburban properties, they should only be used as part of an IPM campaign to reduce overall tick abundance and thereby reduce the incidence of Lyme disease. In practice, the biggest public health impact of forest-lawn barriers might be the visual cue they provide to residents that a high tick zone lies behind the barrier.

Acknowledgments

The author thanks Dr. Joseph Karchesy, Oregon State University, and Terry L. Schulze, Freehold Township, NJ, for generously providing various wood and forest products. The help of Gabrielle Dietrich and Marc C. Dolan in rearing ticks used in these experiments is also appreciated. The author also thanks Dr. Kirby C. Stafford III for a critical reading of the manuscript.

REFERENCES CITED

Benjamin, M.A., E. Zhioua, and R.S. Ostfeld. 2002. Laboratory and field evaluation of the entomopathogenic fungus *Metarhizium anisopliae* (Deuteromycetes) for controlling questing adult *Ixodes scapularis* (Acari: Ixodidae). J. Med. Entomol. 39: 723-728.

Dietrich, G., M.C. Dolan, J. Peralta-Cruz, J. Schmidt, J. Piesman, R.J. Eisen, and J.J. Karchesy. 2006. Repellent activity of fractioned compounds from *Chamaecyparis nootkatensis* essential oil against nymphal *Ixodes scapularis* (Acari: Ixodidae). J. Med. Entomol. 43: 957-961.

Diuk-Wasser, M.A., A.G. Gatewood, M.R. Cortinas, S. Yaremych-Hamer, J. Tsao, U. Kitron, G. Hickling, J.S. Brownstein, E. Walker, J. Piesman, and D. Fish. 2006. Spatiotemporal patterns of host-seeking *Ixodes scapularis* nymphs (Acari: Ixodidae) in the United States. J. Med. Entomol. 43: 166-176.

Duffy, D.C., D.D. Clark, S.R. Campbell, S. Gurney, R. Perello, and N. Simon. 1994. Landscape patterns of abundance of *Ixodes scapularis* (Acari: Ixodidae) on Shelter Island, New York. J. Med. Entomol. 31: 875-879.

Falco, R.C. and D. Fish. 1988. Prevalence of *Ixodes dammini* near the homes of Lyme disease patients in Westchester County, New York. Am. J. Epidemiol. 127: 826-830.

Falco, R.C. and D. Fish. 1991. Horizontal movement of adult *Ixodes dammini* (Acari: Ixodidae) attracted to CO_2-baited traps. J. Med. Entomol. 28: 726-729.

Hayes, E.B. and J. Piesman. 2003. How can we prevent Lyme disease? N. Eng. J. Med. 348: 2424-2430.

Mather, T.N., D.C. Duffy, and S.R. Campbell. 1993. An unexpected result from burning vegetation to reduce Lyme disease transmission risks. J. Med. Entomol. 30: 642-645.

Maupin, G.O., D. Fish, J. Zultowsky, E.G. Campos, and J. Piesman. 1991. Landscape ecology of Lyme disease in a residential area of Westchester County, New York. Am. J. Epidemiol. 133: 1105-1113.

Panella, N.A., M.C. Dolan, J.J. Karchesy, Y. Xiong, J.

Peralta-Cruz, M. Khasawneh, J.A. Montenieri, and G.O. Maupin, 2005. Use of novel compounds for pest control: Insecticidal and acaricidal activity of essential oil components from heartwood of Alaska Yellow Cedar. J. Med. Entomol. 42: 352-358.

Panella, N.A, J. Karchesy, G.O. Maupin, J.C. Malan, and J. Piesman. 1997. Susceptibility of immature *Ixodes scapularis* (Acari:Ixodidae) to plant-derived acaricides. J. Med. Entomol. 34: 340-345.

Patrican, L.A. and S.A. Allan. 1995. Application of desiccant and insecticidal soap treatments to control *Ixodes scapularis* (Acari: Ixodidae) nymphs and adults in a hyperendemic woodland site. J. Med. Entomol. 32: 859-863.

Piesman, J. 2006. Strategies for reducing the risk of Lyme borreliosis in North America. Int. J. Med. Microbiol. 296 (Suppl 1): 17-22.

Schulze, T.L. and R.A. Jordan. 2005. Influence of meso- and microscale habitat structure on focal distribution of sympatric *Ixodes scapularis* and *Amblyomma americanum* (Acari: Ixodidae). J. Med. Entomol. 42: 285-294.

Schulze, T.L. and R.A. Jordan. 2006. *Assessment and management of vector tick populations in New Jersey*. Freehold Township Health Department, Freehold Township, NJ.

Schulze, T.L., R.A. Jordan, and R.W. Hung. 1995. Suppression of subadult *Ixodes scapularis* (Acari: Ixodidae) following removal of leaf litter. J. Med. Entomol. 32: 730-733.

Stafford III, K.C. 2004. *Tick management handbook*. Connecticut Agricultural Experiment Station, New Haven.

Stafford III, K.C. and L.A. Magnarelli. 1993. Spatial and temporal patterns of *Ixodes scapularis* in southeastern Connecticut. J. Med. Entomol. 30: 762-771.

Stafford III, K.C., J.S. Ward, and L.A. Magnarelli. 1998. Impact of controlled burns on the abundance of *Ixodes scapularis* (Acari: Ixodidae). J. Med. Entomol. 35: 510-513.

Wilson, M.L. 1986. Reduced abundance of adult *Ixodes dammini* (Acari: Ixodidae) following destruction of vegetation. J. Econ. Entomol. 79: 693-696.

Zhioua, E., M. Browning, P.W. Johnson, H.S. Ginsberg, and R.A. LeBrun. 1997. Pathogenicity of the entomopathogenic fungus *Metarhizium anisopliae* (Deuteromycetes) to *Ixodes scapularis* (Acari: Ixodidae). J. Parasitol. 83: 815-818.