Lyme Disease and its Transmission, Geography and Ecology in Virginia

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Lyme Disease

Three Stages of Infection

• **Early Localized Infection (3-30 days)**
  Bull’s-eye rash (EM Rash), fever, headache & muscle or joint aches, and swollen glands.

• **Early Disseminated Infection (1-4 mos.)**
  May cause one or more of the following symptoms in some patients: multiple EM rashes, severe headaches, pain, tingling or numbness in extremities, Bell’s palsy, and cardiac (heart block) or neurological symptoms.

• **Late Disseminated Stage (3 mos. to yrs.)**
  May cause one or more of the following symptoms in a small proportion of patients: severe arthritis (pain and swelling) of large joints [mostly knees], fatigue, or neurological and/or cognitive disorders.
The Lyme Disease - EM Rash

The erythema-migrans (EM) Rash may occur in > 80 % of cases - it typically causes little sensation and may not be noticed if it is under hair on the scalp, or on a person’s back side; it typically grows to >4 inches in diameter.

It may come in a variety of shapes - does not always appear as a bull’s-eye pattern – is sometimes just a large red patch.
Lyme Disease Incidence by Age Group, Virginia, 2012

Cases per 100,000 Population (within age group)

Age Group

Change in Lyme Disease Rate by County from 2005 to 2013

Cases per 100,000 population
- 0.1 to 4.9
- 5 to 9.9
- 10 to 24.9
- 25 to 49.9
- 50 to 99.9
- 100+
Virginia Incidence of Lyme Disease Cases by County in 2015

2015 Virginia Lyme Disease Cases per 100,000 Population

Case Rates
2015

0.00
0.01 - 5.00
5.01 - 10.00
10.01 - 25.00
25.01 - 50.00
50.01 - 100.00
100.01 - 377.00
Geographic distribution of Lyme disease cases in Virginia from 2008 to 2015, based on the number of cases per unit area*

* Number of cases per unit area = cases per square (squares are 5.25 km. on a side in a grid pattern overlaid on Virginia; the Lyme case locations are patient residential geo-coordinates). Map created using empirical Bayesian Kriging.
Geographic Lyme disease incidence based on number of cases per census block group in Virginia from 2008 to 2015

Map created using a geospatial analysis called empirical Baysian Kriging.
Associations between Lyme disease and human population density, and Lyme disease and elevation in Virginia
Lyme Disease Transmission Ecology

Factors that may help explain greater Lyme disease incidence at higher elevations and greater incidence in suburbanized areas?
The main vector of Lyme disease to people is the nymph stage blacklegged tick - active from mid-spring to mid-summer.

**Blacklegged Tick (Ixodes scapularis)**

- **Adult female (af)**
- **Adult male (am)**
- **Nymph (n)**
- **Larva (l)**

- = Tick stages known to feed on people.
- = Tick stage causing the most disease transmission

Adult blacklegged ticks do not commonly bite people, but may sometimes transmit Lyme disease to people during the fall, winter and early spring months.
Differences between “northern variant” and “southern variant” blacklegged ticks

“Southern variant” (SV) tick larvae and nymphs feed primarily on lizards, but may sometimes be found on small rodent species that live in forest environments.

SV nymphs are unlikely to be infected with the Lyme disease agent \((\text{Borrelia burgdorferi})\) because their lizard hosts do not carry it.

SV nymphs are very unlikely to bite people because they mostly stay down in the leaf litter where they would not encounter a person’s foot; they are also difficult to collect on drag cloths.

SV adult ticks are very much like “northern variant” adults; they feed primarily on deer and are easily collected from deer.
Feeding preferences and habits of the “northern variant” blacklegged tick

Larvae feed primarily on small rodent species and birds found on the forest floor.

Nymphs have much broader feeding preferences than the adult ticks; have been collected from over 100 different species of animals as well as people; are relatively easy to collect with drag cloths, and are important Lyme vectors to people.

Adult blacklegged ticks prefer to feed on deer but may occasionally be found feeding on other animals such as dogs, cats, foxes, or people.
Geography of blacklegged tick “variants” in Virginia

Historically blacklegged ticks were only found in the coastal regions of Virginia and prior to 1990, they had not been found in the Piedmont or Mountain regions.

Virginia’s coastal blacklegged tick populations behave very much like “southern variant ticks”; adult ticks are easy to find on deer in the fall, but nymphs are difficult to find on the forest floor, during the late spring and early summer.

Since 1990, blacklegged ticks have gradually moved southwestward across Virginia’s Piedmont and Mountain regions and these ticks behave like “northern variant” ticks.

This may explain the prevalence of Lyme disease in the Piedmont and Mountain regions of Virginia.
White-footed mice are highly competent reservoirs of *Borrelia burgdorferi*.

Play a major role in maintaining the Lyme infection cycle in the blacklegged tick population.

They can be infected with *B. burgdorferi* and remain infectious to feeding ticks for up to six months.

Photo by Jim Schulz / Chicago Zoological Soc.
Competent and non-competent host species

Other animal species known to have high to moderate competence as *B. burgdorferi* reservoirs include:

- Eastern chipmunks
- Meadow voles
- Short-tailed shrews
- Masked shrews
- American robins

Many other animal species have low competence as reservoirs; cannot be infected by *B. burgdorferi*, and play little or no role in its transmission.

Some low or non-competent host species include:

- Eastern grey squirrels
- Raccoons
- Skunks
- Opossums
- Lizards
- White tailed deer, etc.
The effects of forest environment on reservoir hosts and Lyme transmission

Studies (by Ostfeld and others) have shown that animal species diversity in forest environments influences the *B. burgdorferi* infection rate in ticks.

If a mixture of competent and non-competent host species are available for larval and nymph stage ticks to feed on, this can dilute *B. burgdorferi* transmission.

**Dilution Effect:** Infected nymph stage ticks feed on non-competent reservoir animals and their infection cannot be passed on to other ticks that feed on these same animals.
Animal species diversity is greatest in undisturbed forests and lowest in fragmented and disturbed forest environments.

There is a mixture of competent and non-competent host species, and *B. burgdorferi* transmission is diluted.

= competent reservoir species
The effect of forest environment

In fragmented and disturbed forest environments, white-footed mice often become the predominant forest species.

Competent reservoirs predominate and cause high rates of *B. burgdorferi* infection in the local tick population.
Effect of suburbanization on white-footed mouse habitat

Suburbanization often results in fragmented and disturbed forest environments that could favor white-footed mouse populations.

It is possible that man-made structures around the edges of suburban forests (e.g., sheds, wood piles, scrap piles, etc.) provide added nesting sites for the white-footed mouse population.
The role of white-tailed deer

White-tailed deer are important because:

Deer serve as the prime mating ground for adult blacklegged ticks; unmated female ticks cannot lay viable eggs.

Deer also serve as the primary source of blood for egg production by female blacklegged ticks.
The role of white-tailed deer

Each deer can feed many female ticks.

Each engorged female tick that drops off of a deer may have the potential to lay up to 3,000 eggs.
The role of white-tailed deer

Studies have shown that total elimination of the local white-tailed deer population results in a 99% reduction of the local blacklegged tick population (It will also eliminate the lone star tick population).

Blacklegged tick population density is generally positively correlated with deer population density.

Higher tick population densities can increase the rate of *B. burgdorferi* transmission by ticks.
White-tailed deer habitats

White-tailed deer prefer forest edge environments.

Feed on vegetation that grows in sun-lit areas along the forest edge and use the forest for refuge.

A square mile of solid forest will support a much smaller deer population than a square mile of fragmented forest.

Fragmented forests have more of the edge habitat and forage that deer require.
Effect of suburbanization on deer habitat

Suburbanization can result in a pattern of fragmented forest and increase white-tailed deer habitat and deer populations.

Deer have adapted well to suburban environments and can survive in relatively densely developed areas.

Suburbanized regions also tend to restrict deer hunting activities to isolated geographic areas.

Deer are smart - properties and neighborhoods that are off-limits to hunters become a refuge for deer during the hunting season.
Overall effect of suburbanization on tick populations and Lyme disease transmission

Fragmented suburbanized forests may result in increased white-tailed deer population density, contributing to increase of local blacklegged tick population density.

Fragmented suburbanized forests may have white footed mice as the predominant forest mammal species, contributing to locally higher rates of Lyme infection in ticks.

Ultimately, the higher tick population densities and their higher rates of infection cause higher rates of Lyme transmission to people in suburban environments.
Acknowledgements:

Local, Regional and Central Office Epidemiologists – Virginia Department of Health (VDH), Division of Surveillance and Investigation

Jim Broyhill, Janet Thomas & Stephanie Crawford – VDH, Division of Environmental Epidemiology

Nelson Lafon – Virginia Dept. Game and Inland Fisheries

Rexford Dwamena, PhD – VDH, Office of Minority Health and Health Equity
Elevation Above Sea Level (Ft.)

- 4501 to 6000 Ft.
- 3001 to 4500 Ft.
- 1801 to 3000 Ft.
- 1201 to 1800 Ft.
- 601 to 1200 Ft.
- 301 to 600 Ft.
- 151 to 300 Ft.
- 0 to 150 Ft.
People per Square Mile by Census Tract, 2010
Geographic density of Lyme disease cases per year from 2008 to 2015