# OF MITES & MEN

# THE ECOLOGY & MANAGEMENT OF LYME DISEASE

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Vector-borne Disease Ecology & Control

@VEClab

@vectorecology

TickEncounter
THE UNIVERSITY OF RHODE ISLAND

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COLLEGE OF THE ENVIRONMENT AND LIFE SCIENCES

NEWVEC
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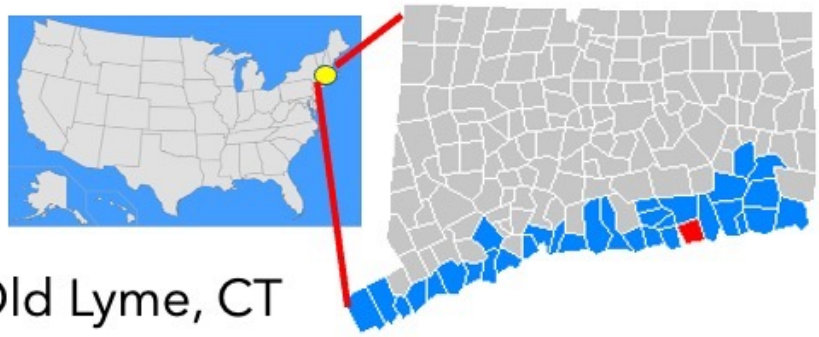
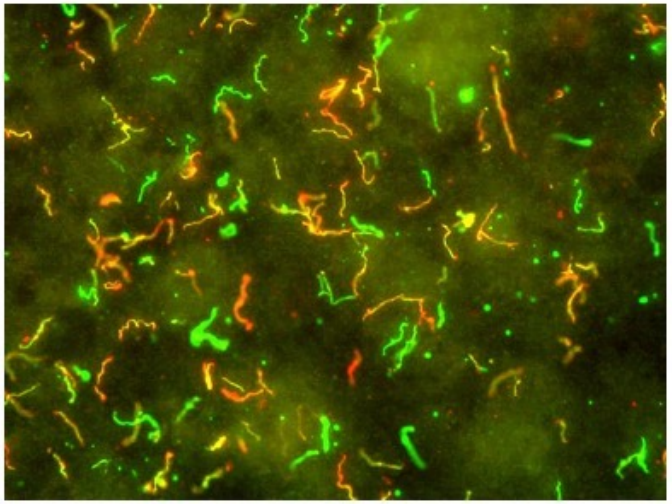
# The discovery of Lyme disease in the US 1970s



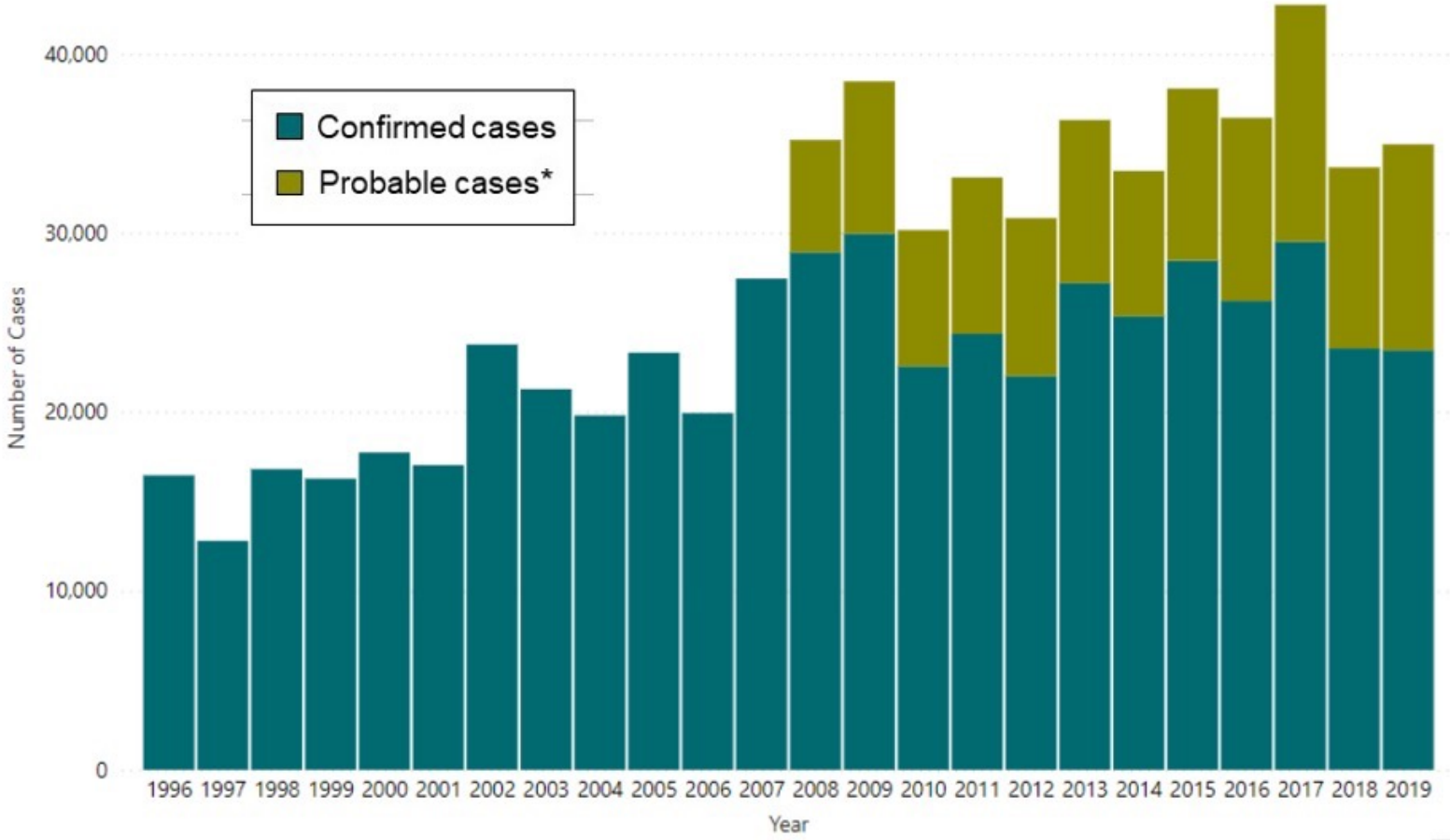
Old Lyme, CT

*Borrelia burgdorferi*

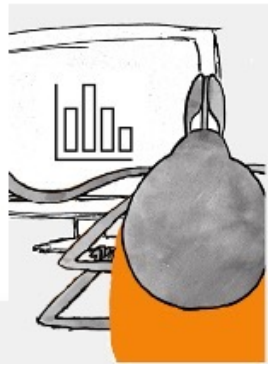


# Lyme disease continues to emerge

# Lyme disease is emerging over time…



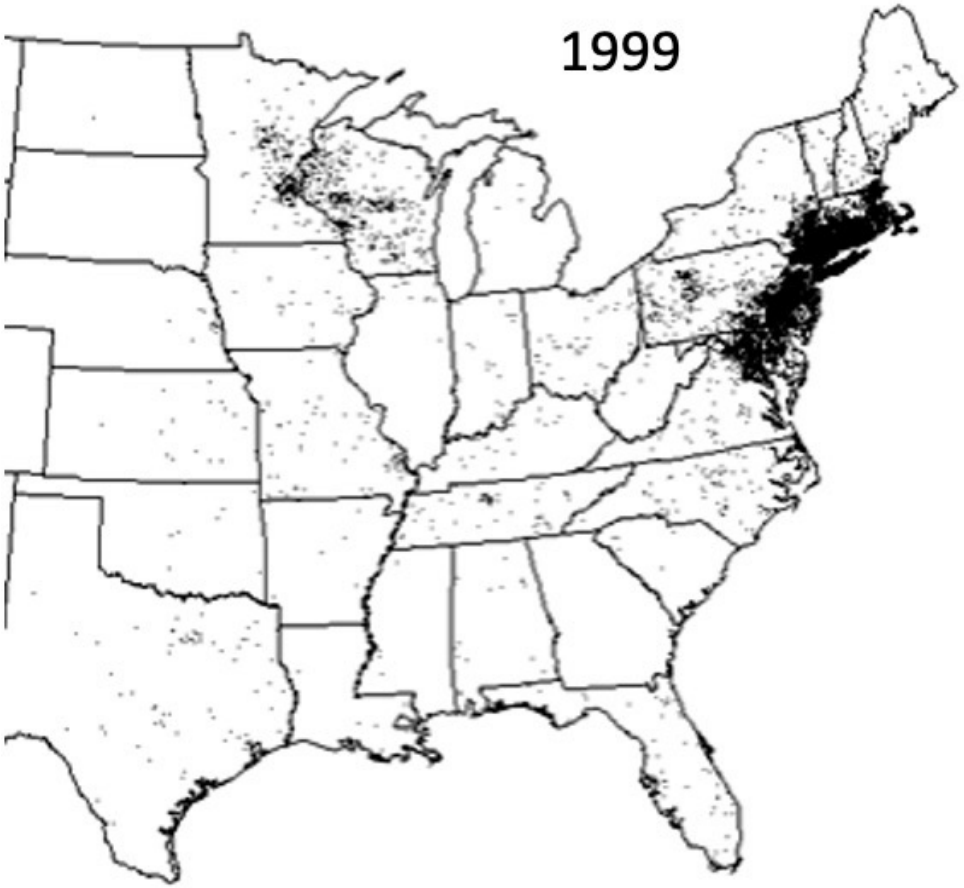

https://www.cdc.gov/lyme/datasurveillance/charts-figures-recent.html



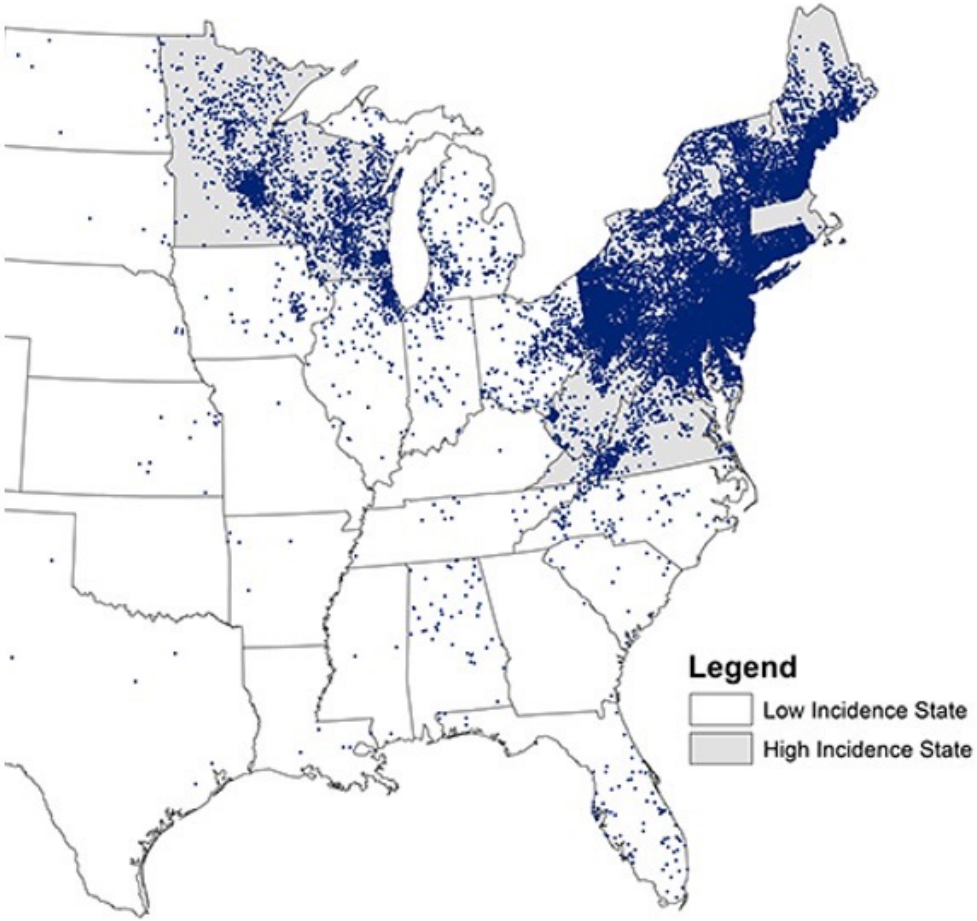
# Lyme disease is emerging over space

>90% cases occur in 7 northern eastern US

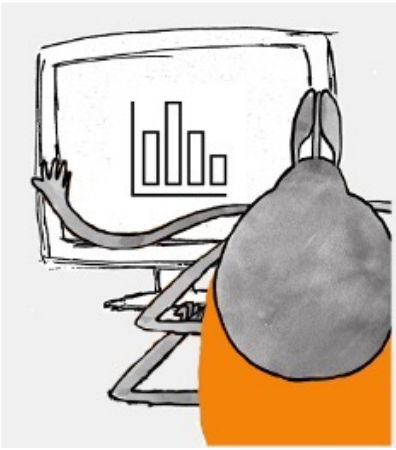
1999



2019

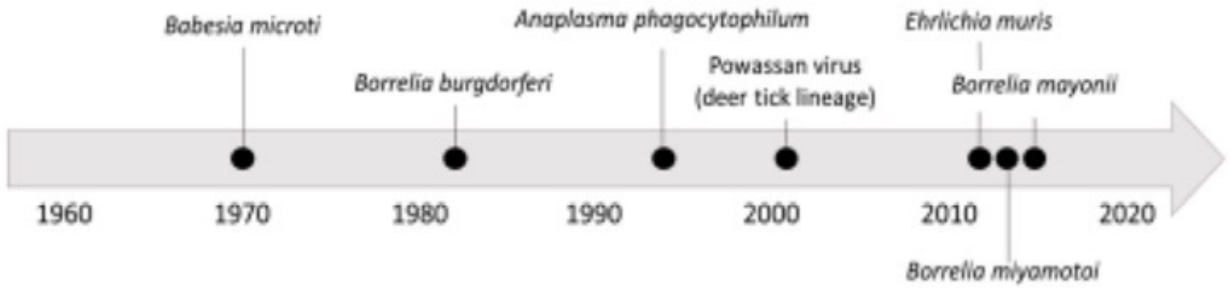


# 476,000 Americans are diagnosed and treated annually for Lyme disease



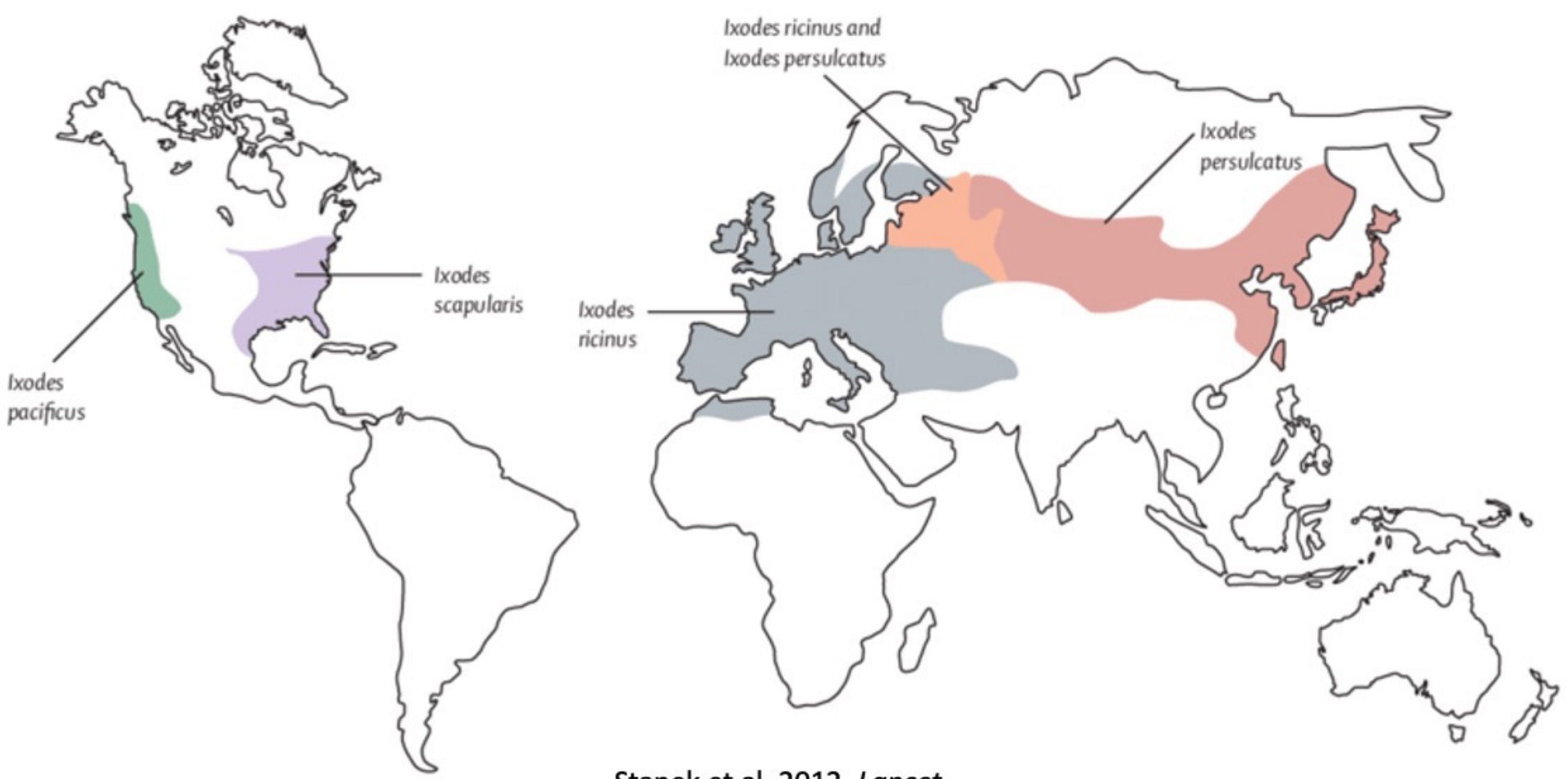
Kugeler et al. 2021
Schwartz et al. 2021

# *Ixodes scapularis*: an increasing public health concern



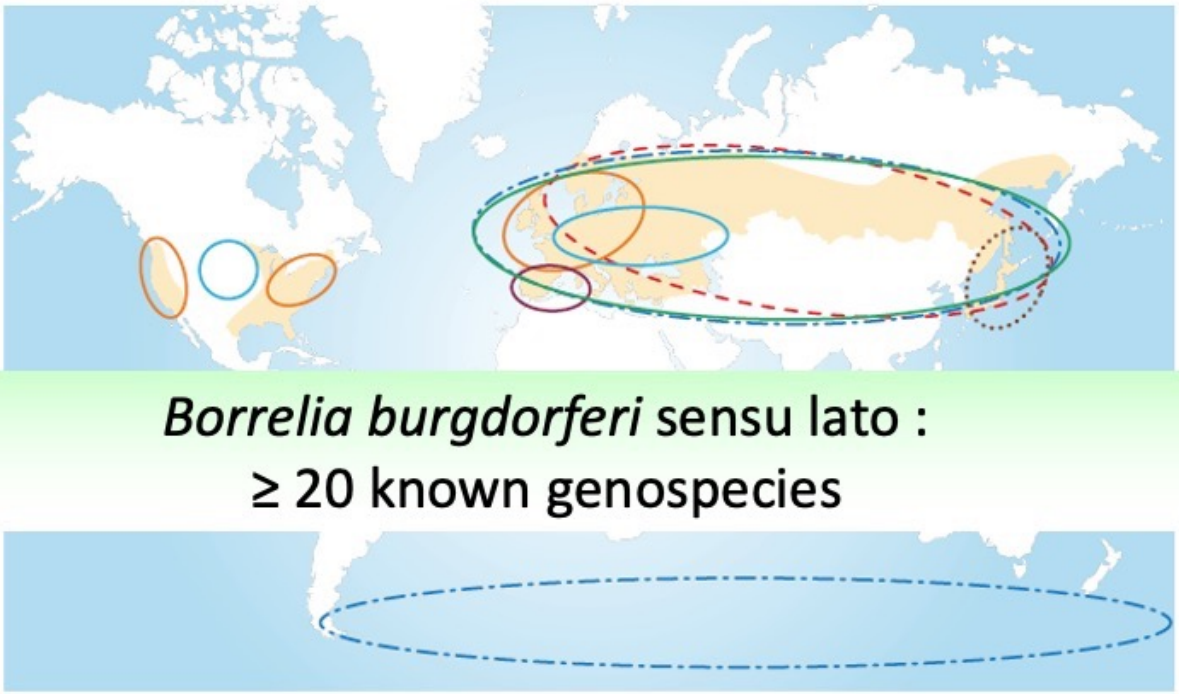

Eisen, RJ and Eisen, L. Trends in Parasitology, 2018. 34:295-309.

# *Borrelia burgdorferi* sensu lato cycles between ticks in the *Ixodes ricinus* complex and their vertebrate hosts




Stanek et al. 2012. *Lancet*.

# Emergence in the global north

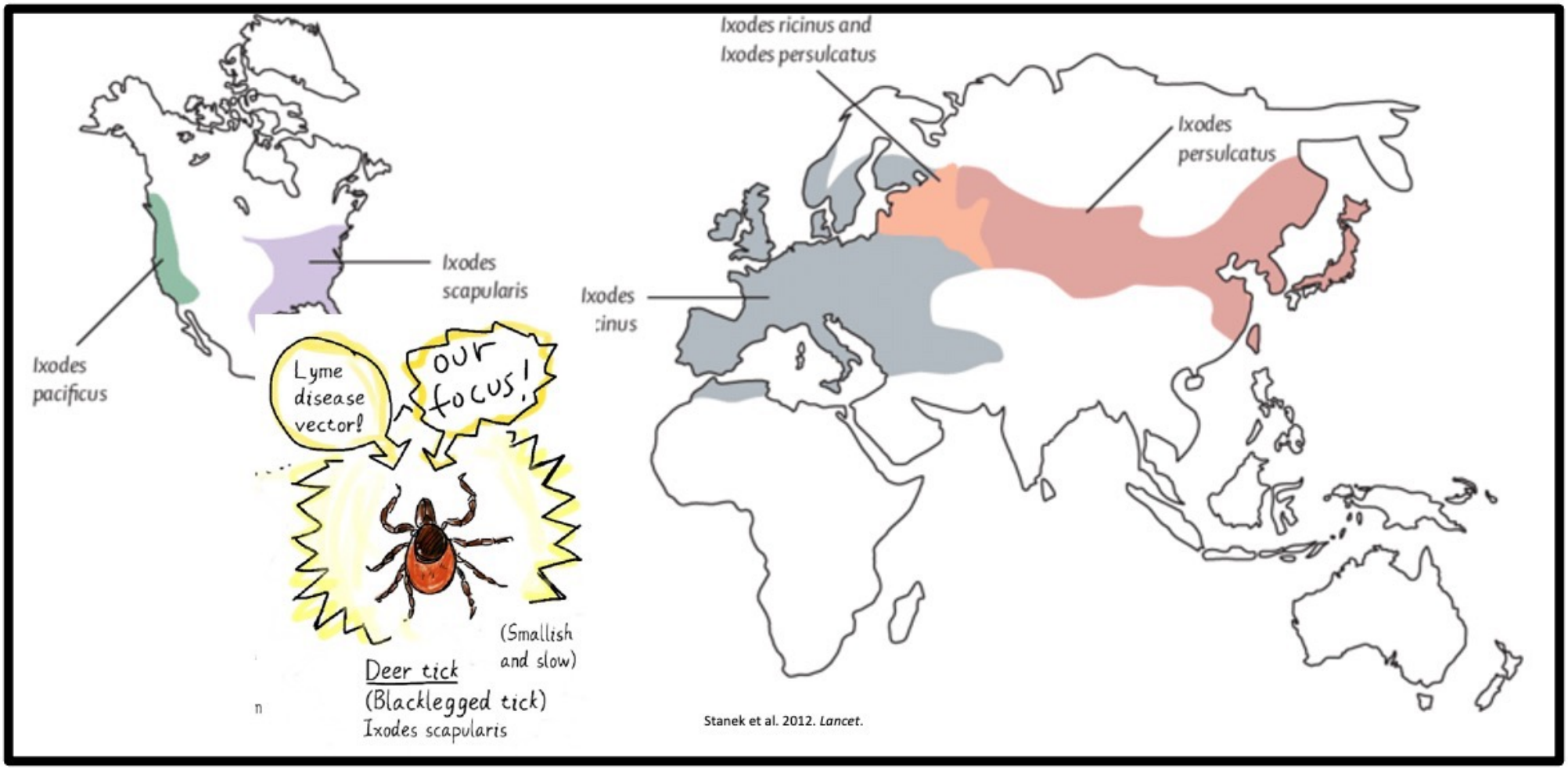



***Borrelia burgdorferi*** **sensu lato :**
**≥ 20 known genospecies**

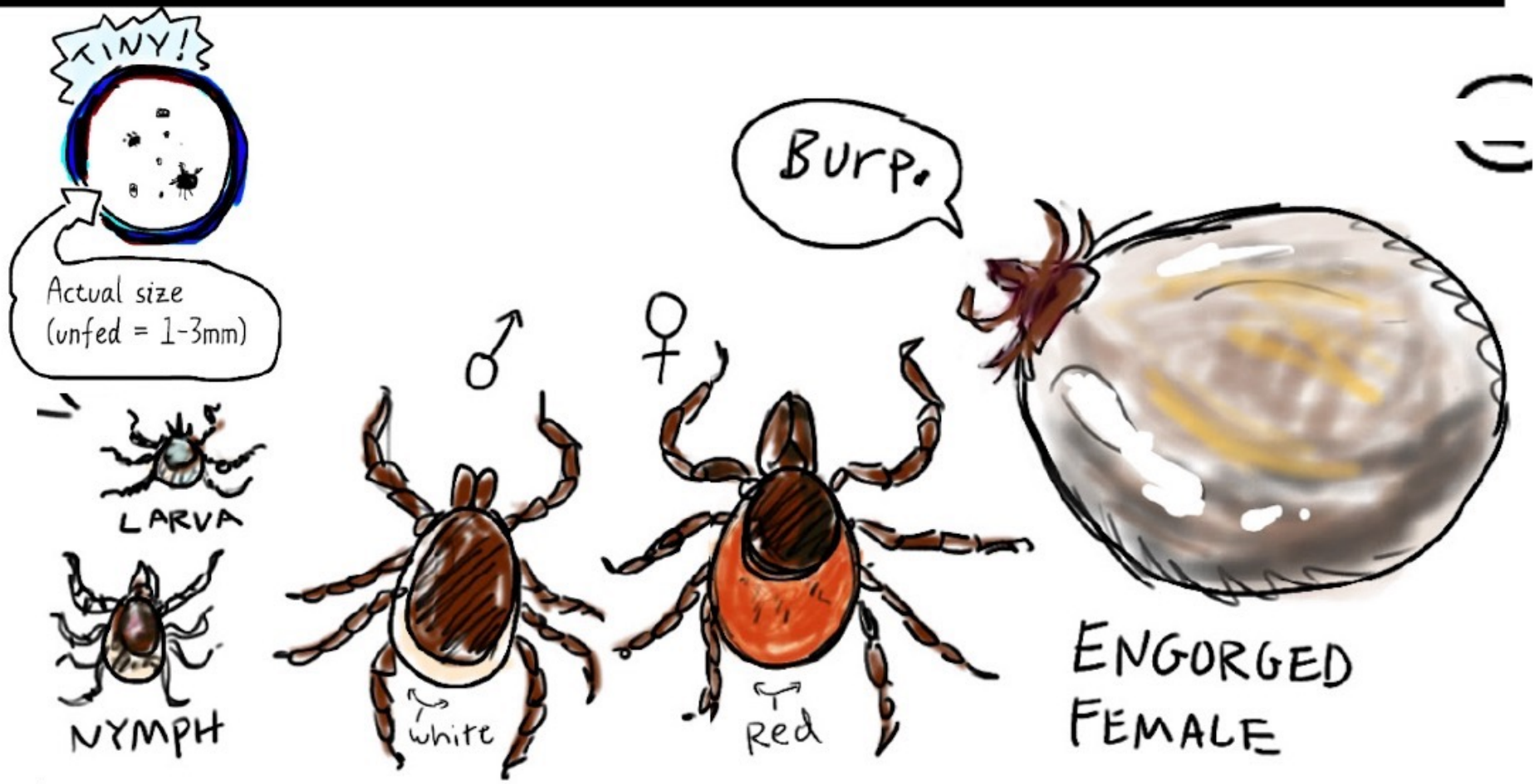
Kurtenbach et al. 2006. *Nature reviews*.

Maintenance of LB enzootic cycles in nature

# *Borrelia burgdorferi* sensu lato vectored by ticks in the *Ixodes ricinus* complex

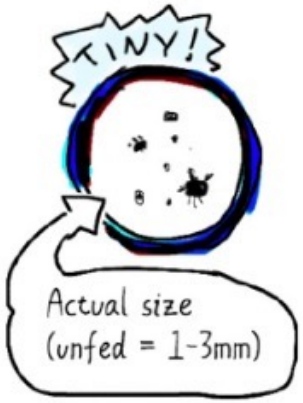


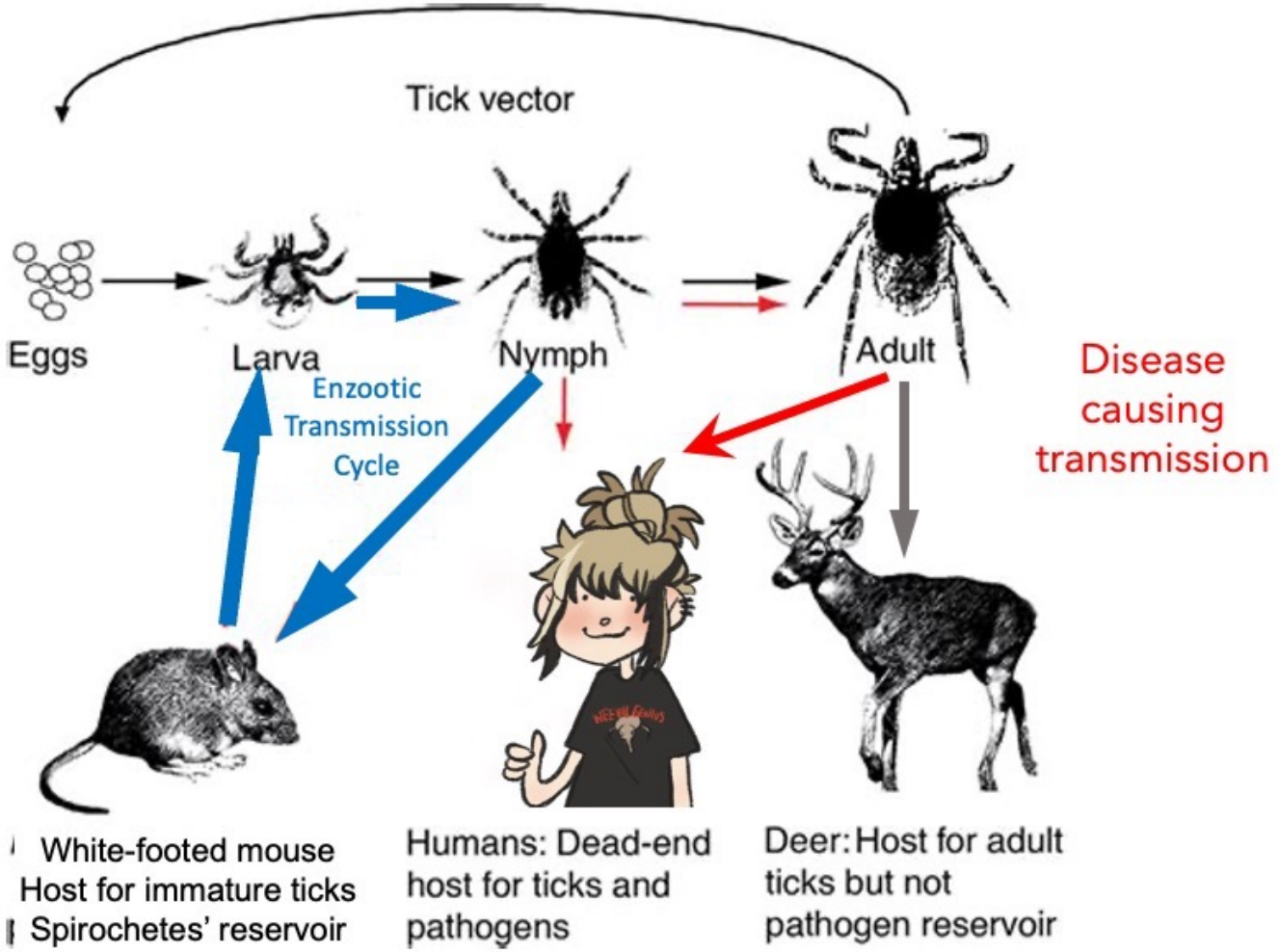
# Require a blood meal to develop and reproduce (females)



Females lay eggs in one batch & then die

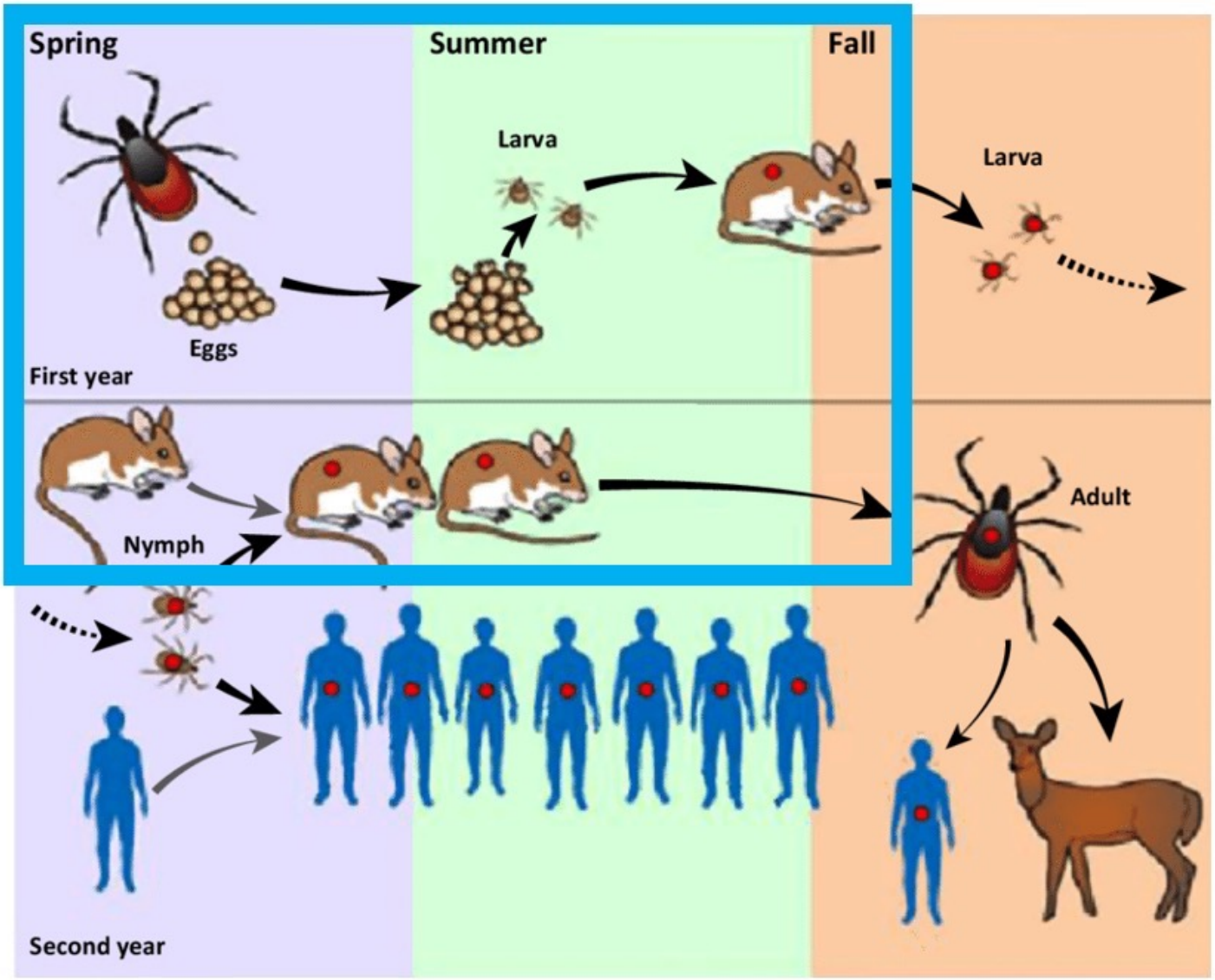
# Enzootic vs Spillover Transmission of Lyme spirochetes



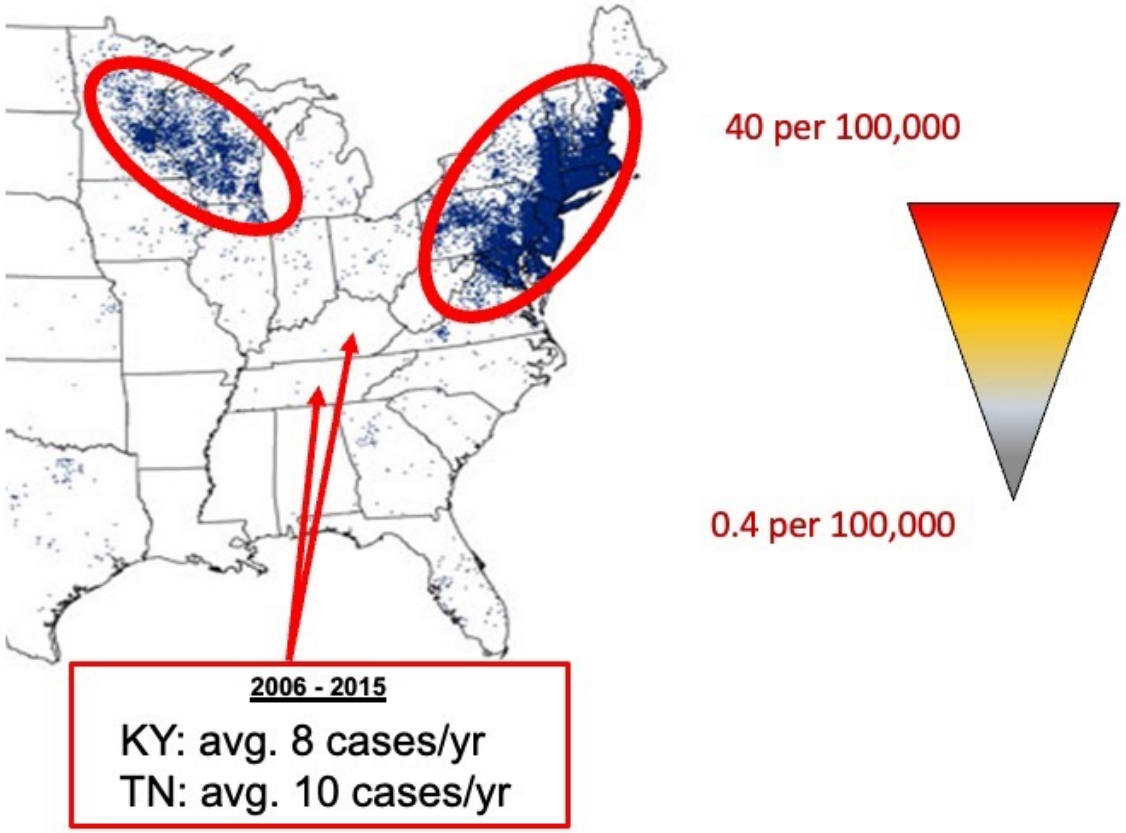
Primary enzootic
Transmission cycle

Maintains
*B. burgdorferi*




Duik-
Wasser
et al. 2015

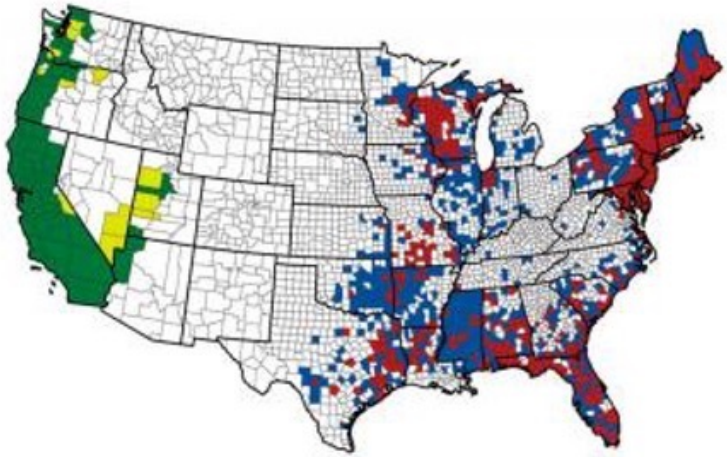
Latitudinal 'gradient' in reported Lyme disease incidence: **~2 orders of magnitude**



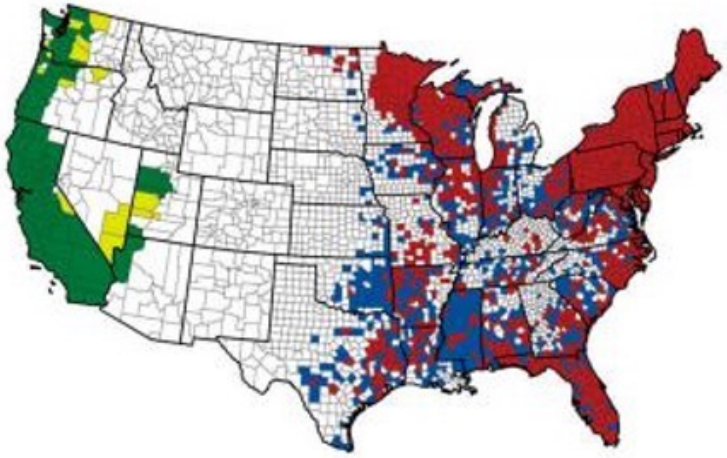
**There is a mismatch between** human disease and vector-tick distribution

1) *Ixodes* abundance in the South is too low to support transmission cycles?

# The blacklegged tick has been spreading!



**1907-1996** (Dennis et al. 1998)

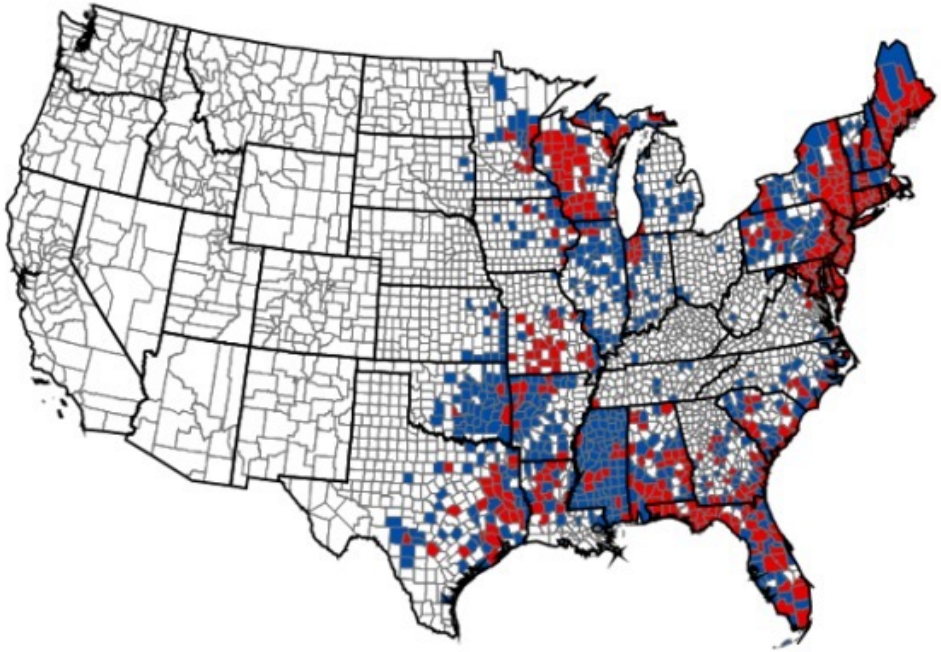


**1907-2015** (Eisen et al. 2016)

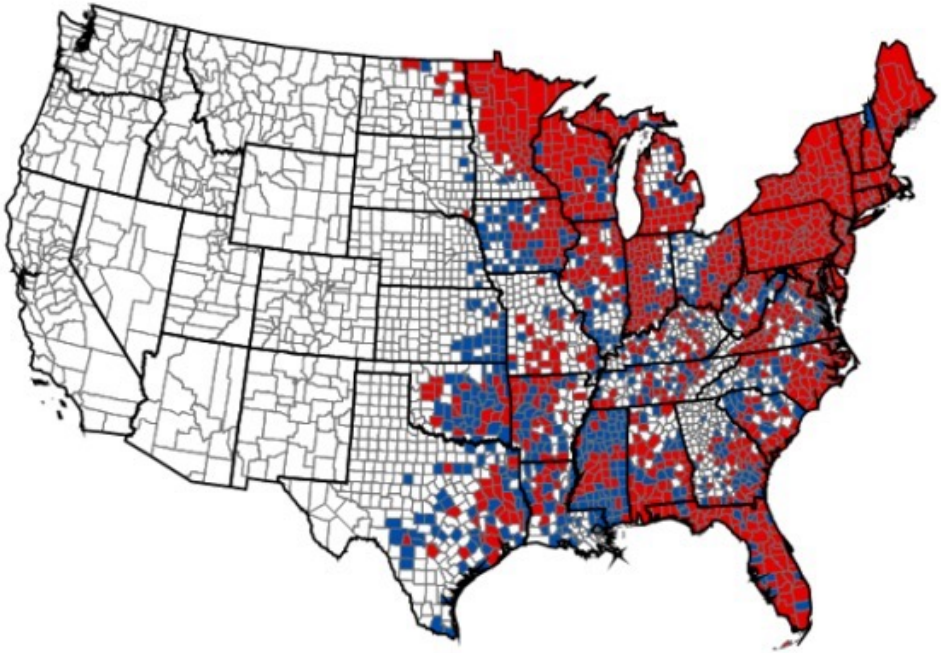
**<u>Established</u> tick populations:**
≥ 6 ticks or 2 life stages in a single year

# Reported Distribution of *I. scapularis* has expanded

1996



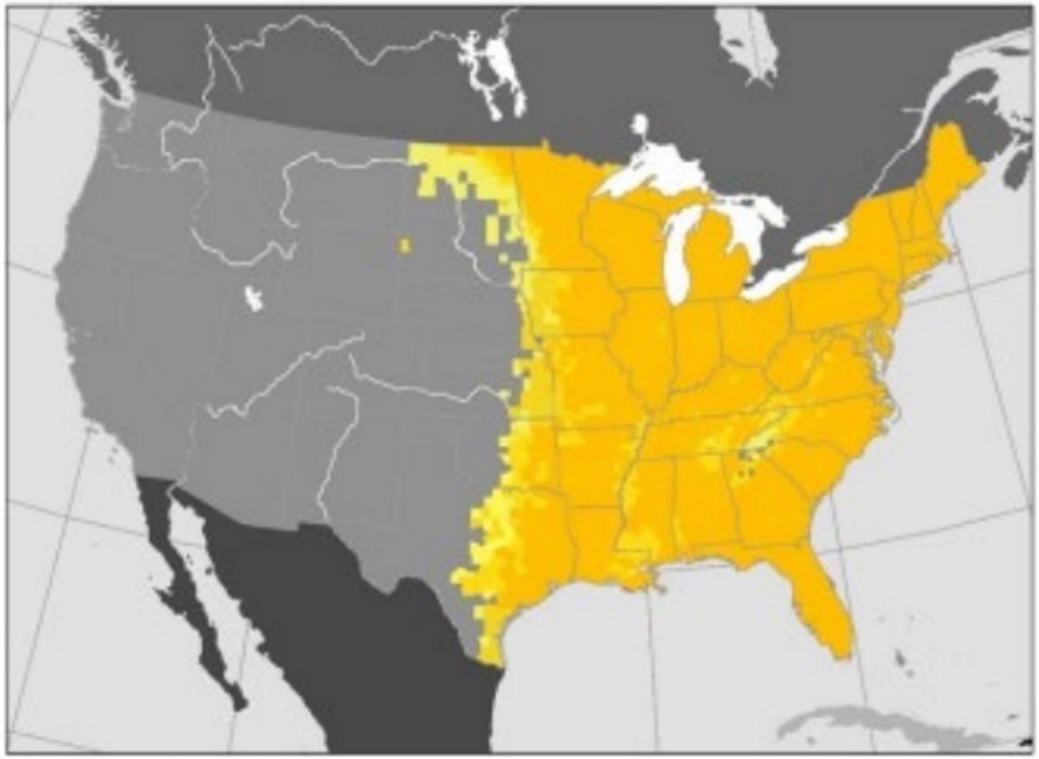
2021



Reported: Fewer than six individual ticks of a single life stage recorded in a single year

Established: Six or more ticks or more than one life stage recorded in a single year

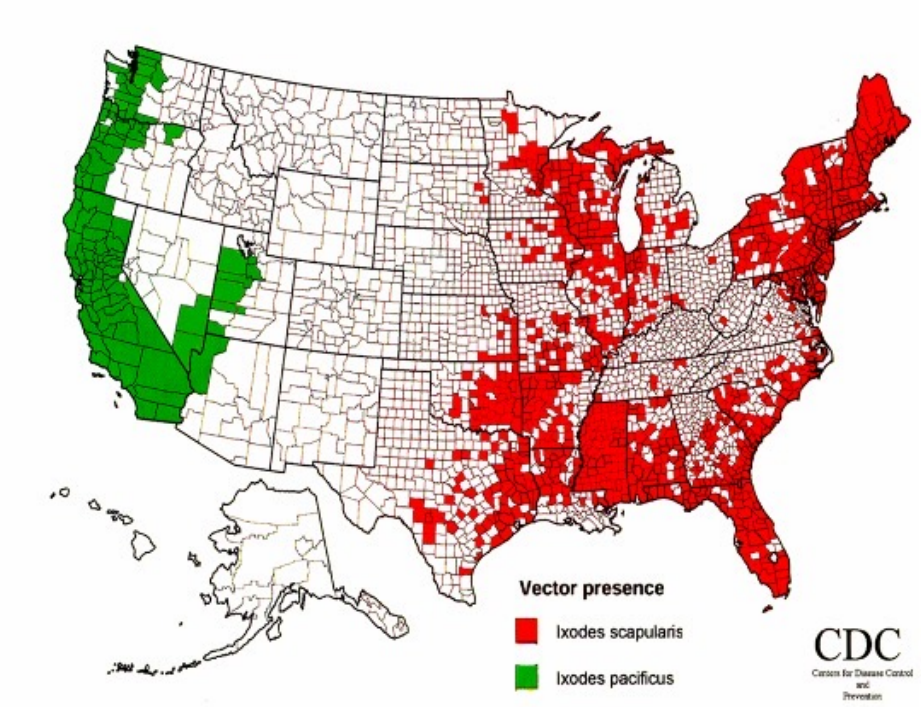
# Distribution of suitable habitat, *Ixodes scapularis*

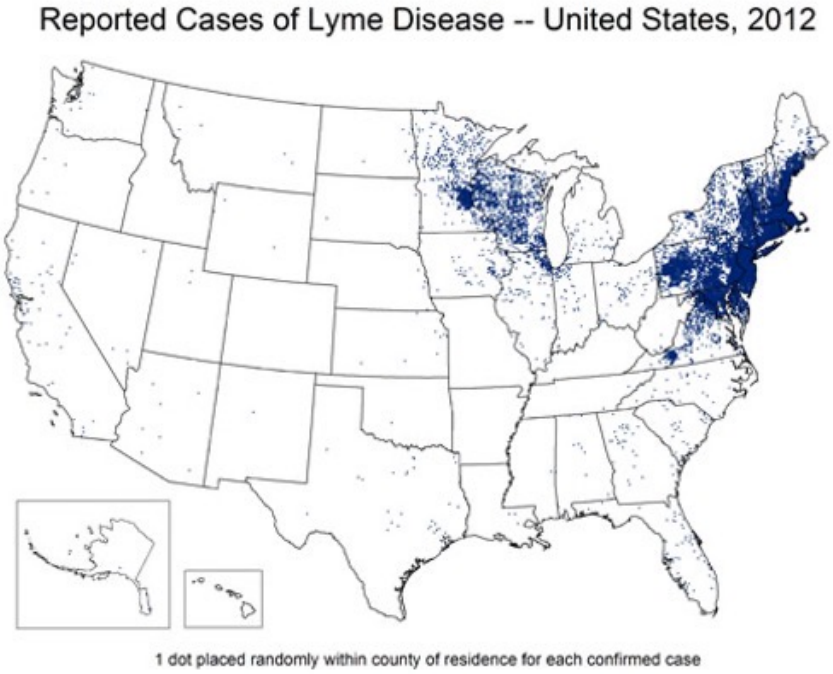


Hahn MB et al. J Med Entomol 2017;54:1104-1106.

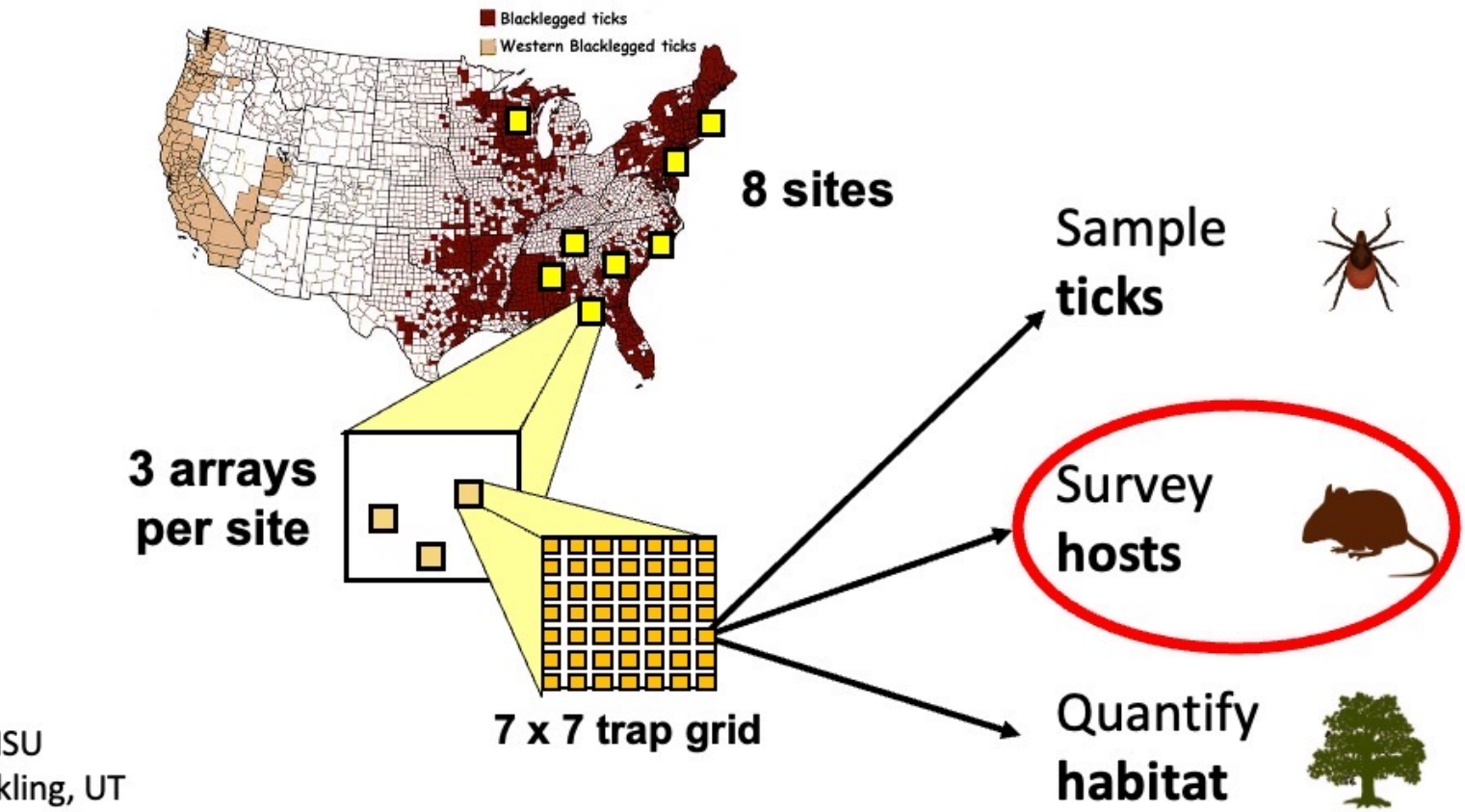
Established: Six or more ticks of more than one life stage recorded in a single year

# Tick distribution vs. Human cases



# Lyme Gradient Project 2010-2015



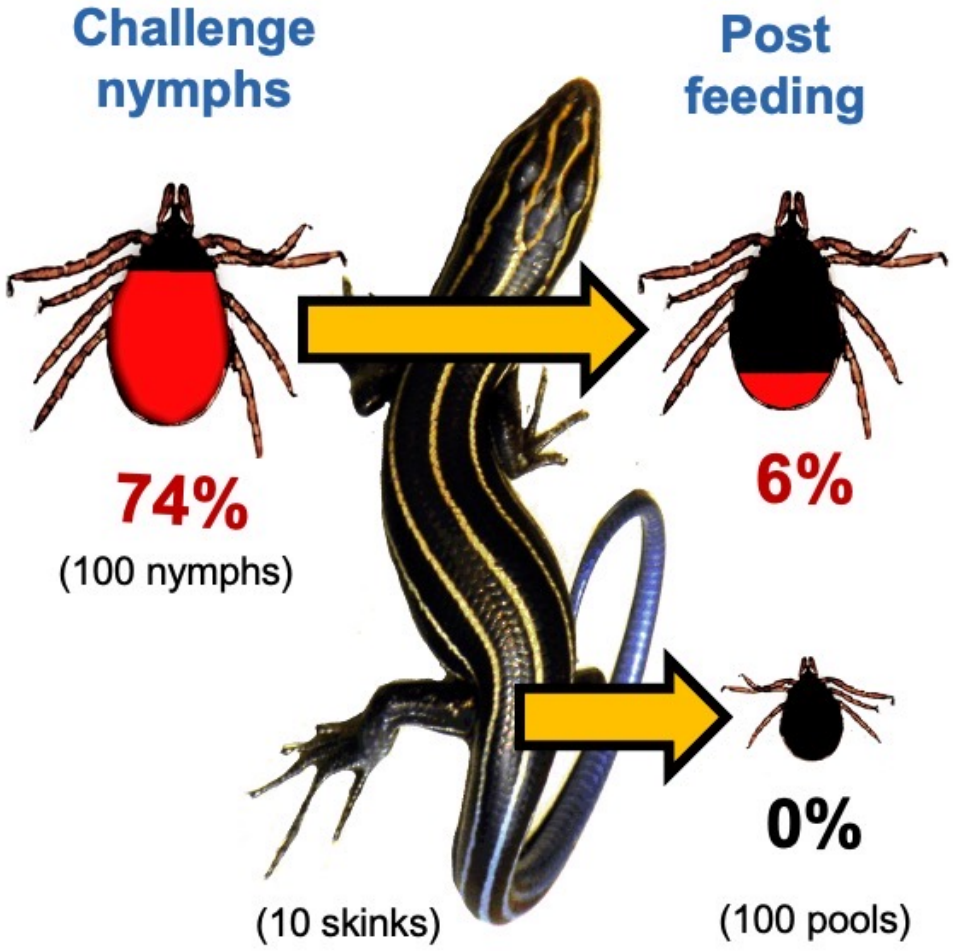

Jean Tsao MSU
Graham Hickling, UT
Howie Ginsberg, URI

# Not all vertebrate hosts equally contribute to enzootic maintenance of Lyme spirochetes

Northeastern US

*Peromyscus leucopus*

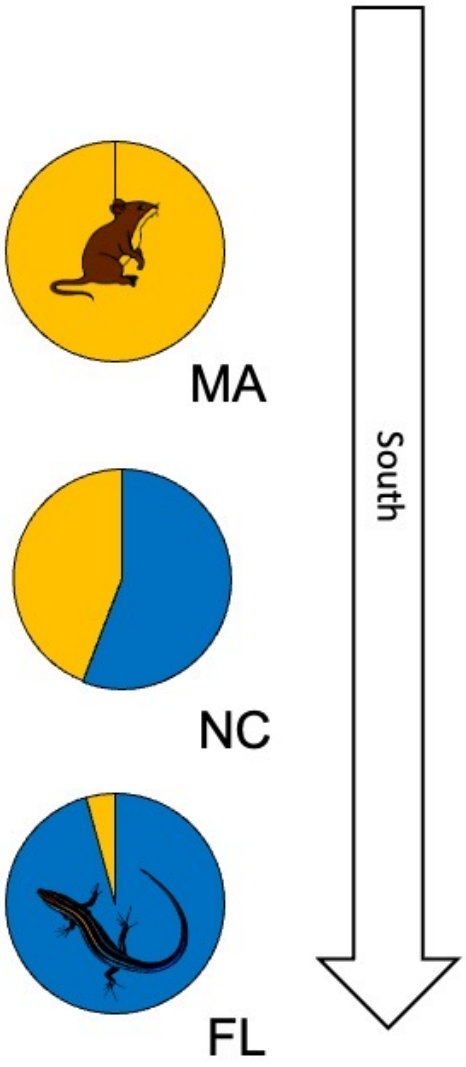
White-footed mouse



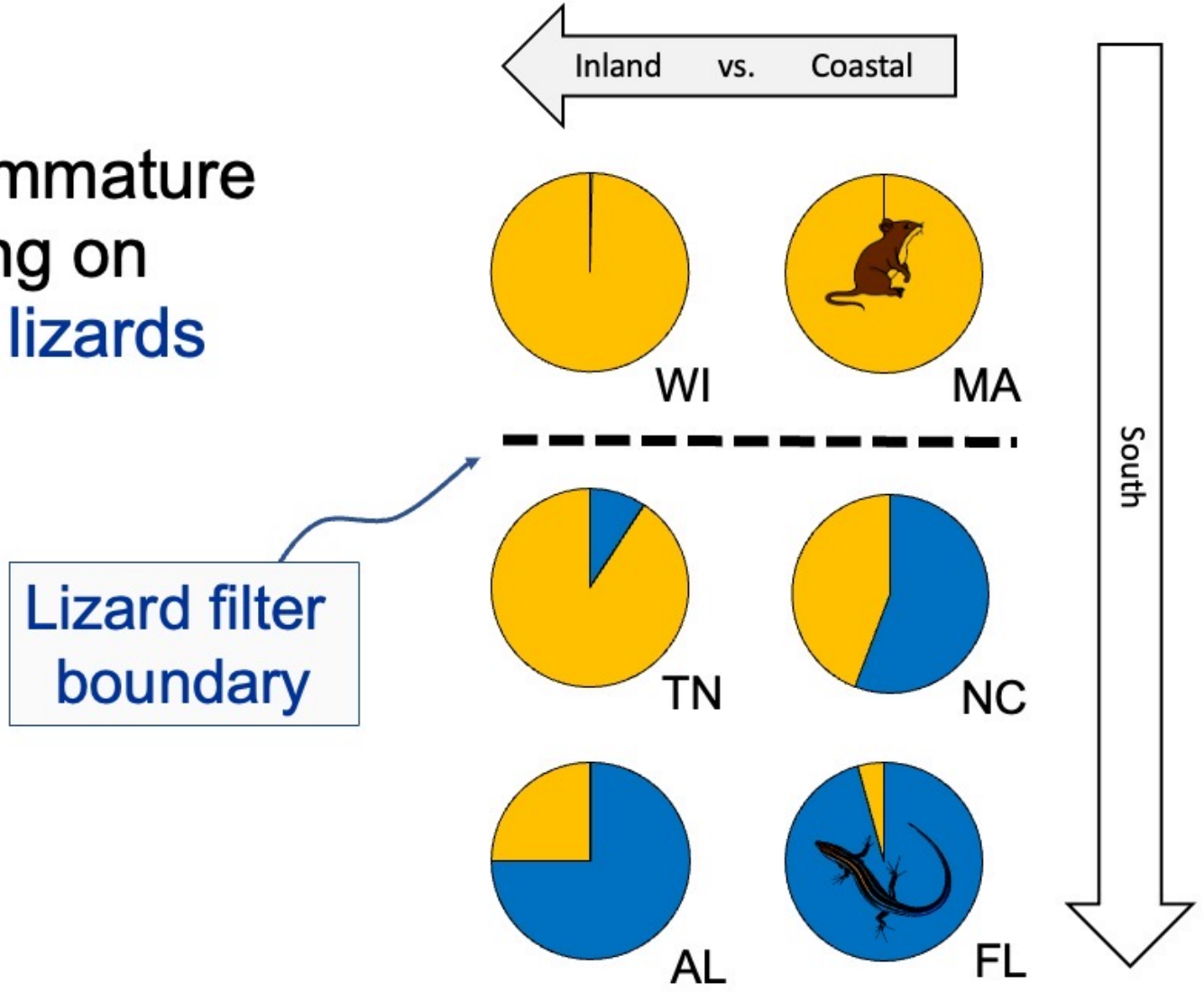

(Nymphs feeding on control mice remained infected)

(100% of control mice produced infected larvae)

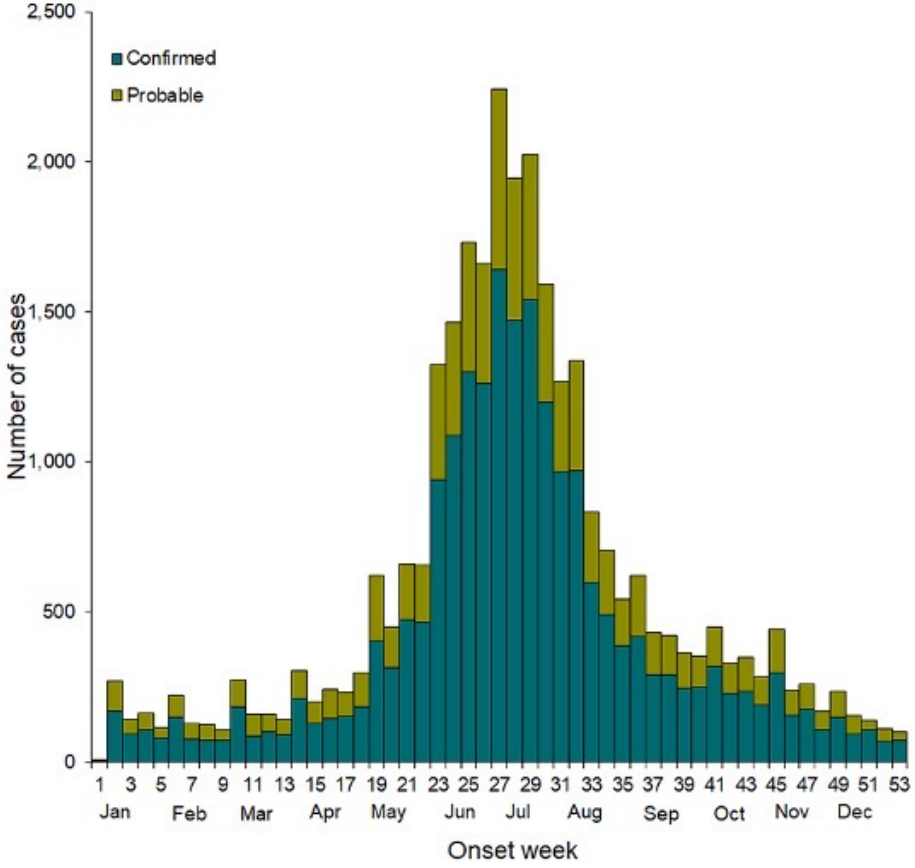
Propn. of immature *Ixodes* feeding on rodents *vs* lizards



Propn. of immature ticks feeding on rodents *vs* lizards

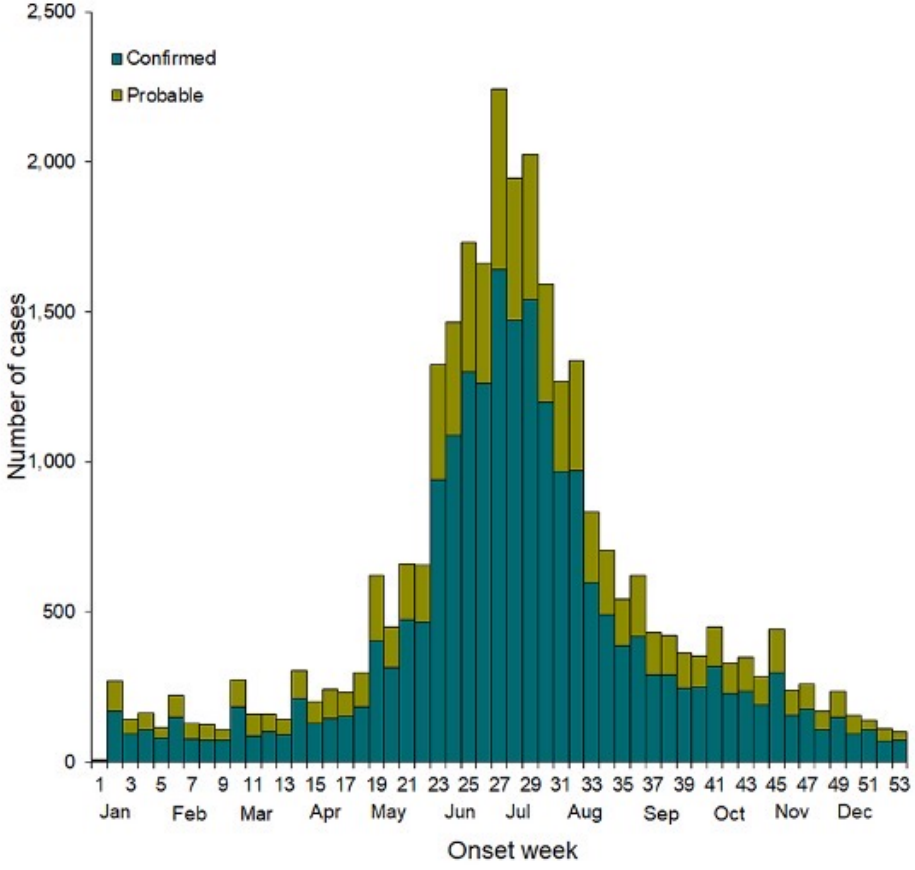


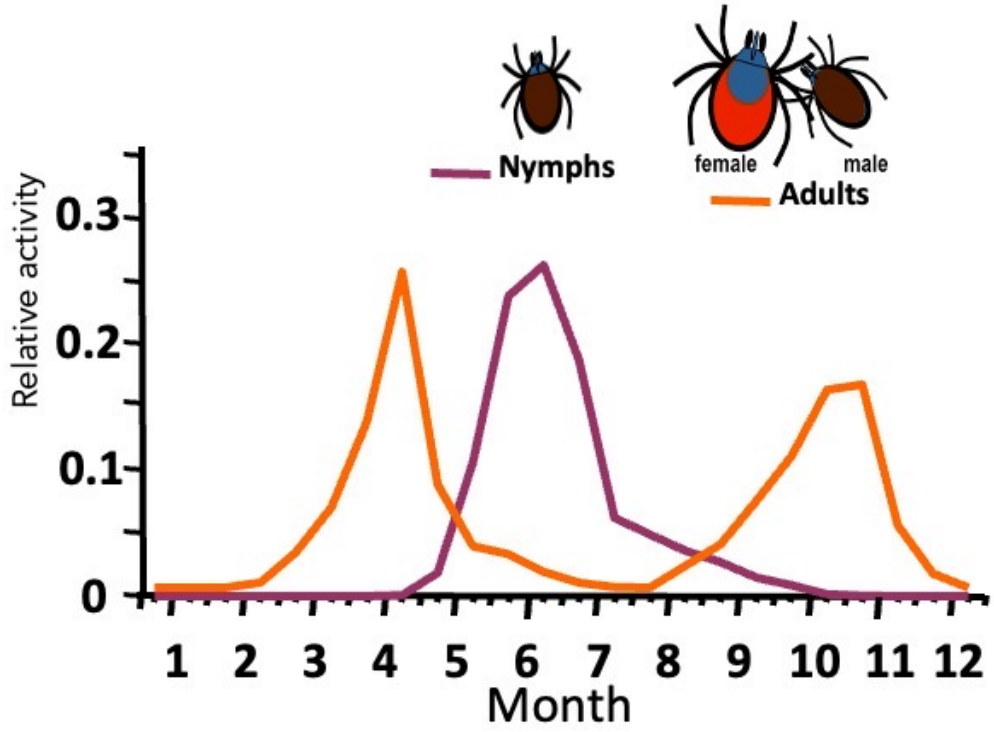
# Lyme disease cases peak in mid summer




Cdc,.gov

# Ticks active 10-12 months of the year

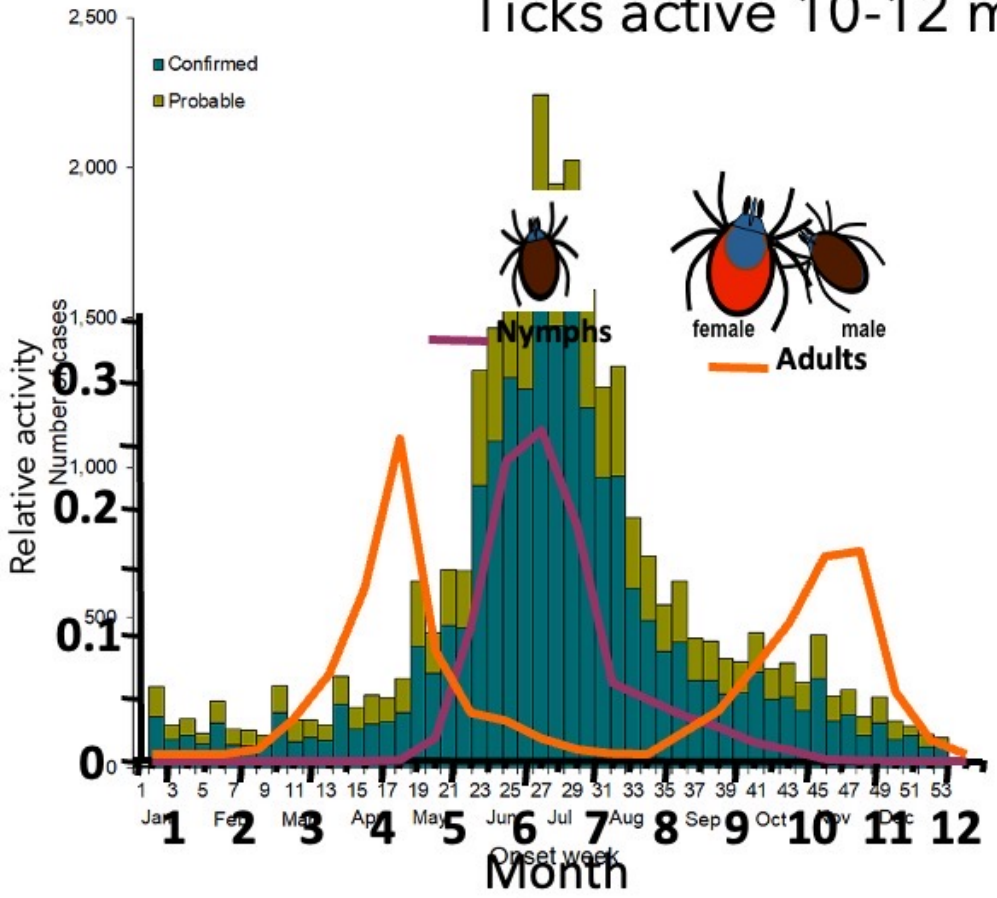



Disease peak coincides with nymphal deer tick abundance

Cdc,.gov

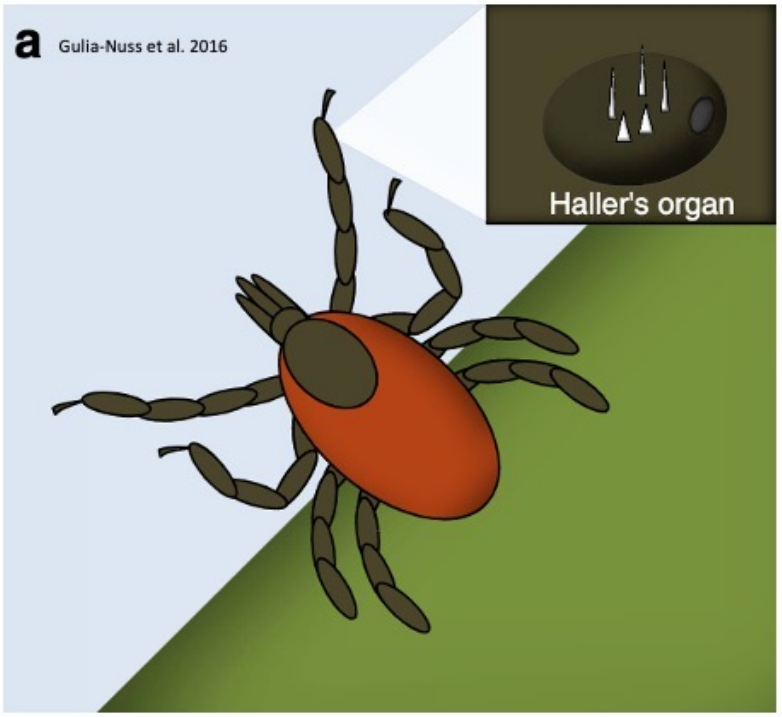
# Ticks active 10-12 months of the year




Disease peak coincides with nymphal deer tick abundance

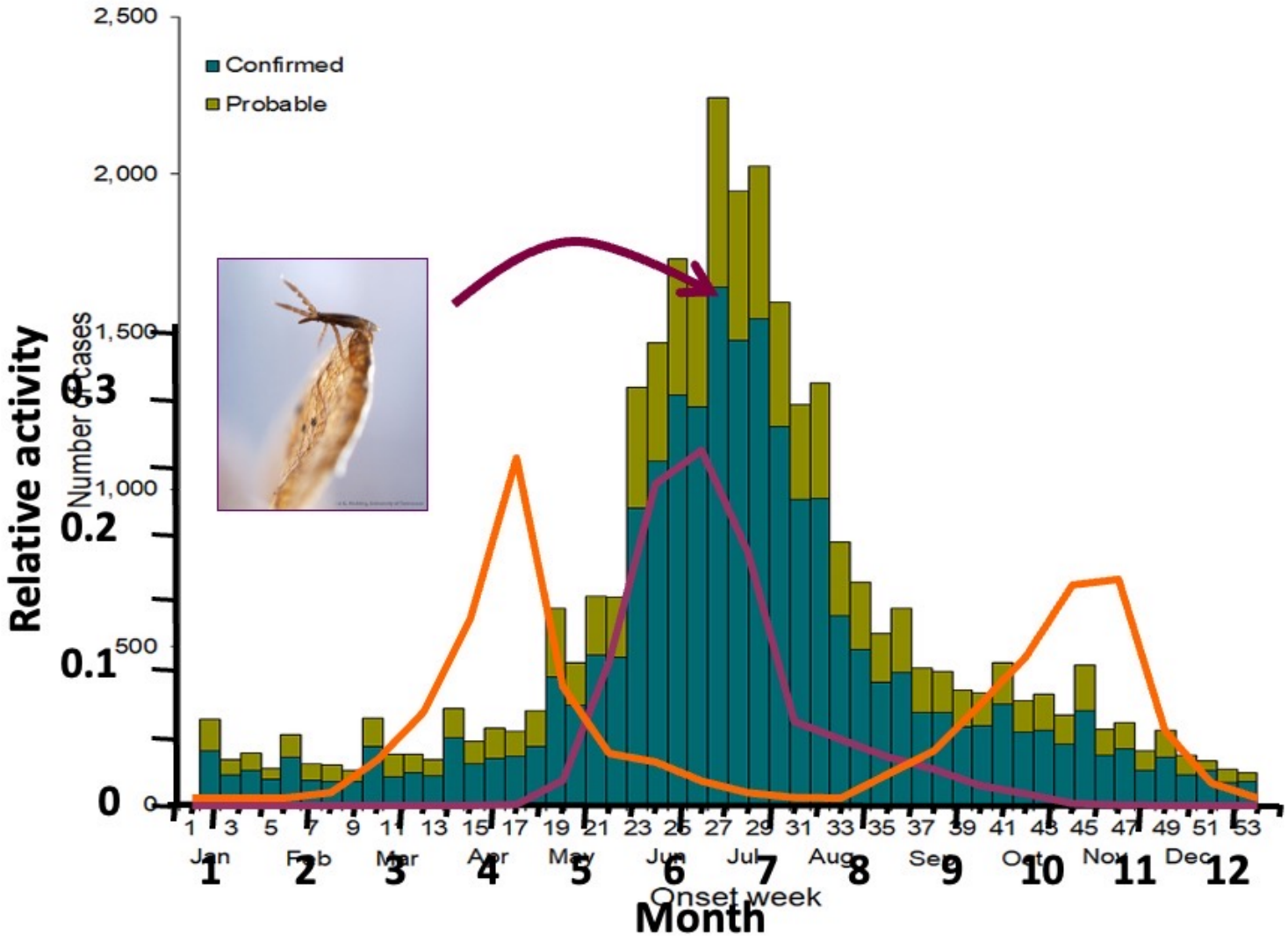
Cdc,.gov

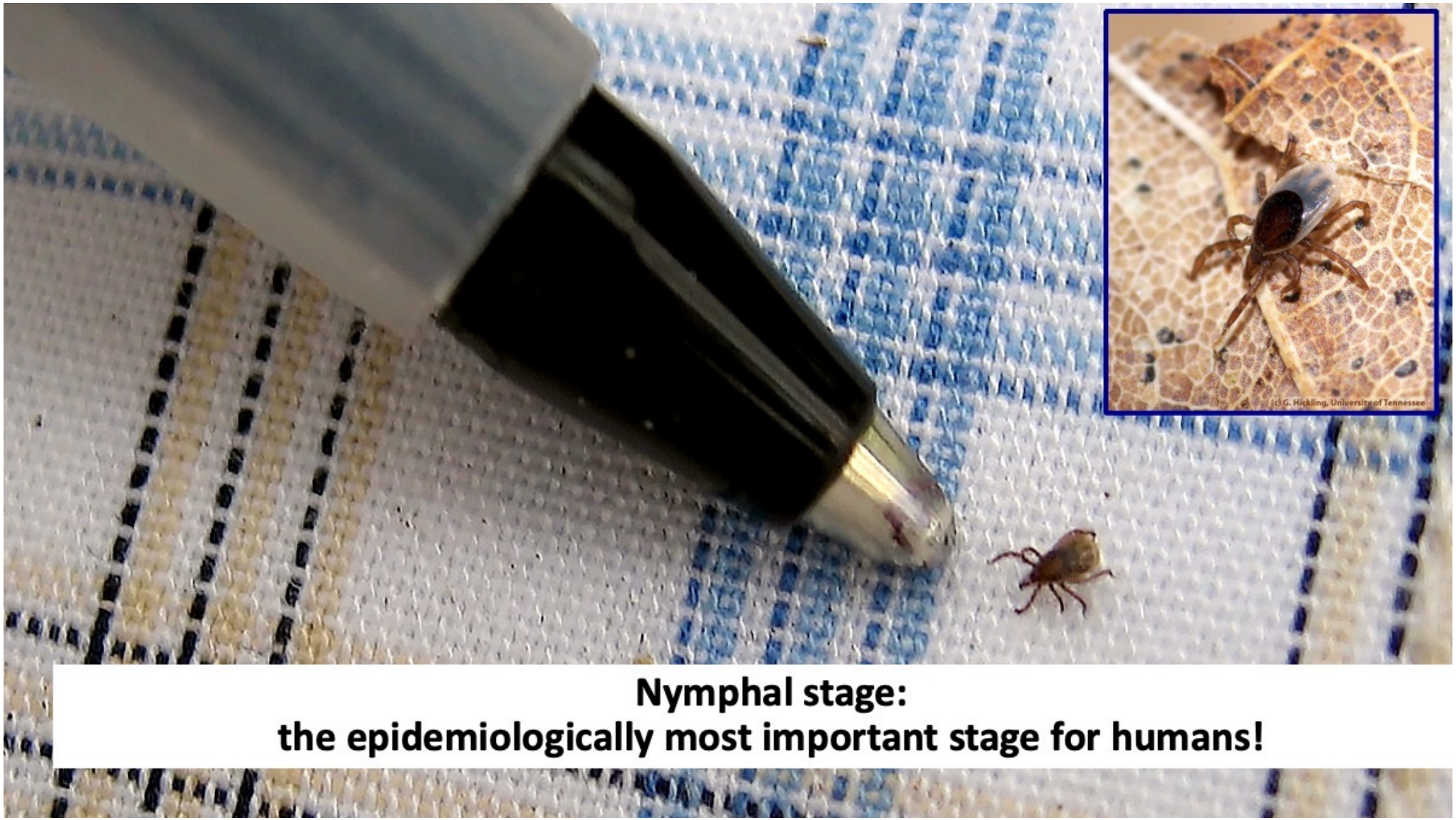
# Host seeking behavior





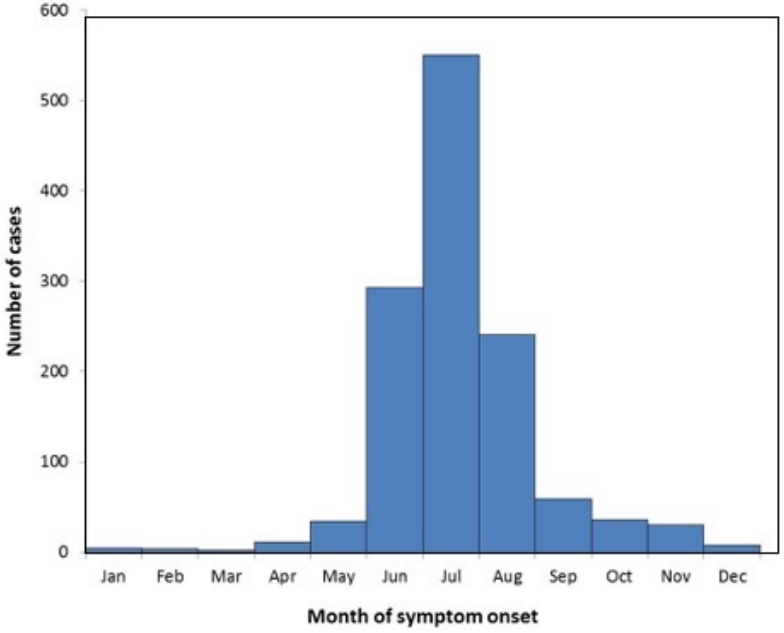
# Tick behavior impacts human Lyme disease risk


2,500
2,000
1,500
1,000
500
0
Confirmed
Probable
Number of cases
Relative activity
0.3
0.2
0.1
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1 2 3 4 5 6 7 8 9 10 11 12
Onset week
Month

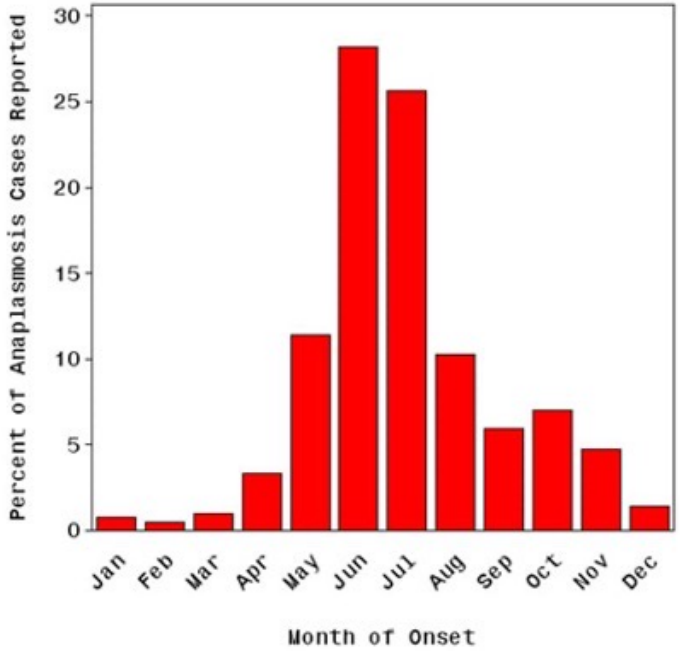



**Nymphal stage:**
**the epidemiologically most important stage for humans!**

The same summer peak is seen for babesiosis and anaplasmosis (different pathogens, same tick)

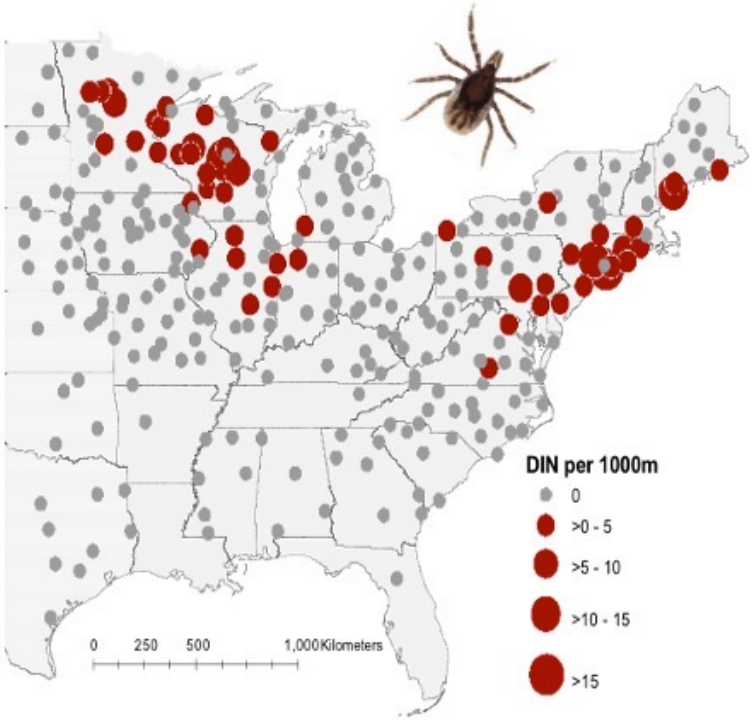



Babesiosis (2013, CDC)




Anaplasmosis (2000-2010, CDC)

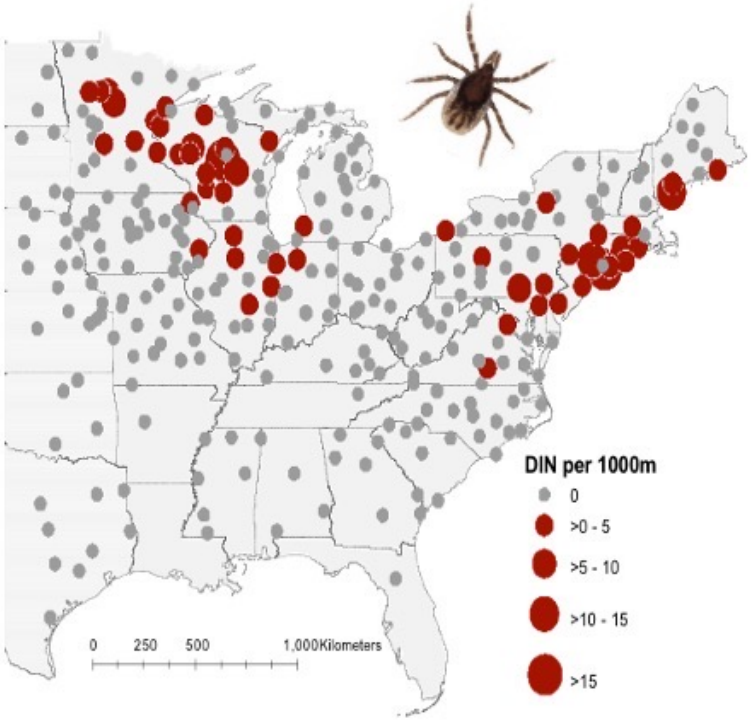
# Distribution of questing *I. scapularis* nymphs




**Density of infected questing nymphs**

(Diuk-Wasser et al. 2012)

# Lyme disease distribution matches QUESTING nymphs distribution




**Density of infected questing nymphs**

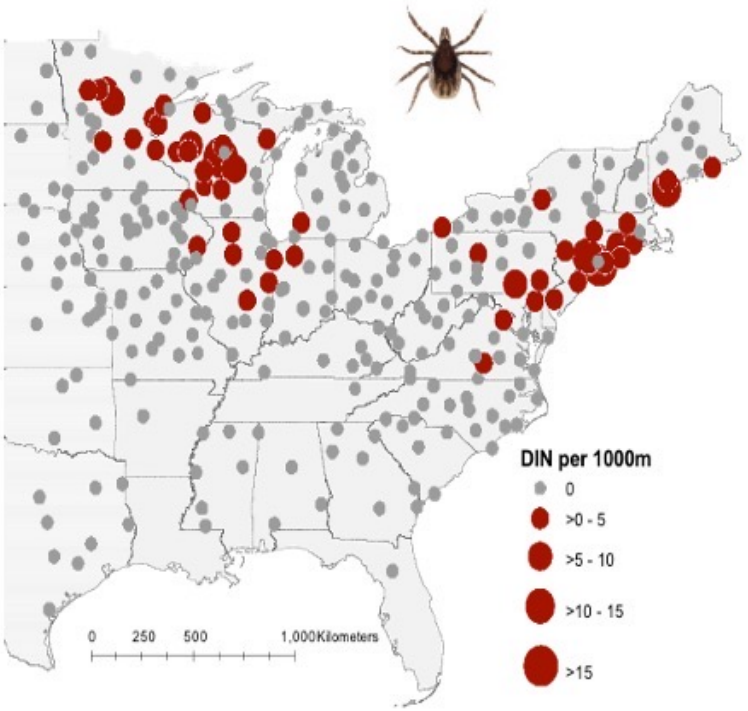
(Diuk-Wasser et al. 2012)

**Lyme disease cases**

(CDC 2012)

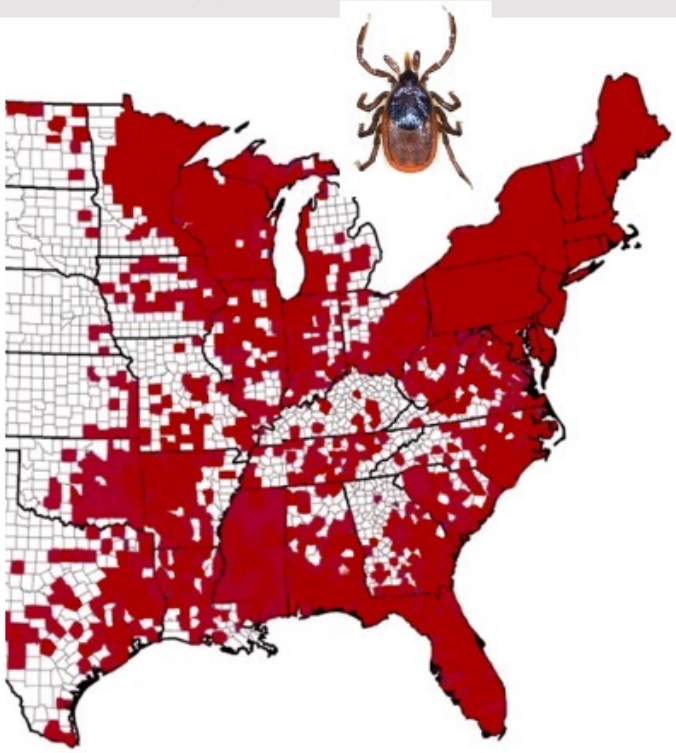
## But …

## does <u>not</u> match the species range of the tick




**Density of infected questing nymphs**

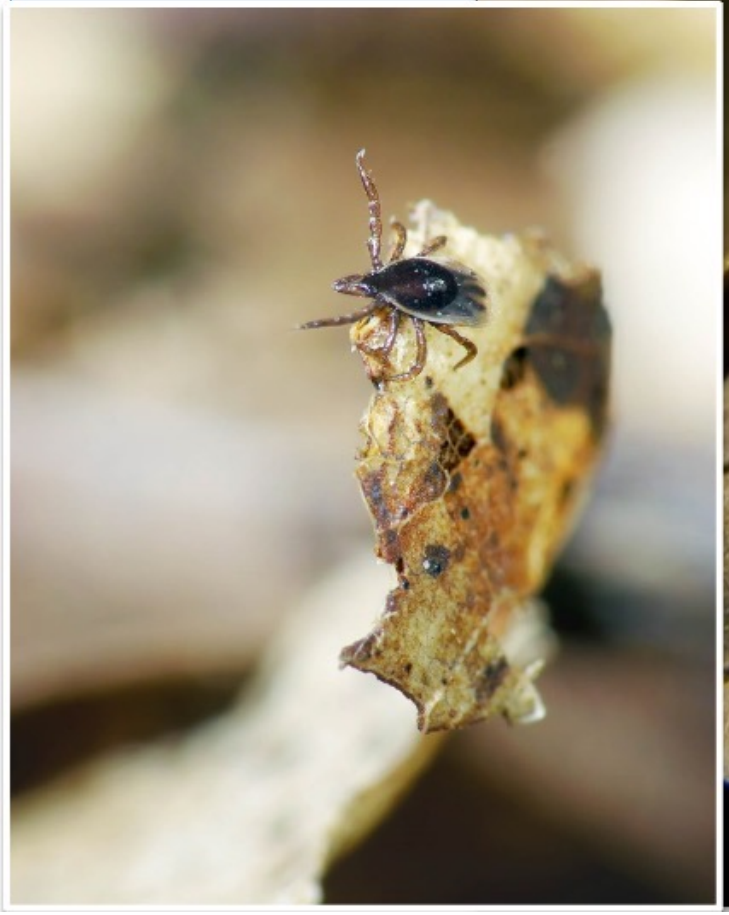
(Diuk-Wasser et al. 2012)



**Counties with *I. scapularis* present**

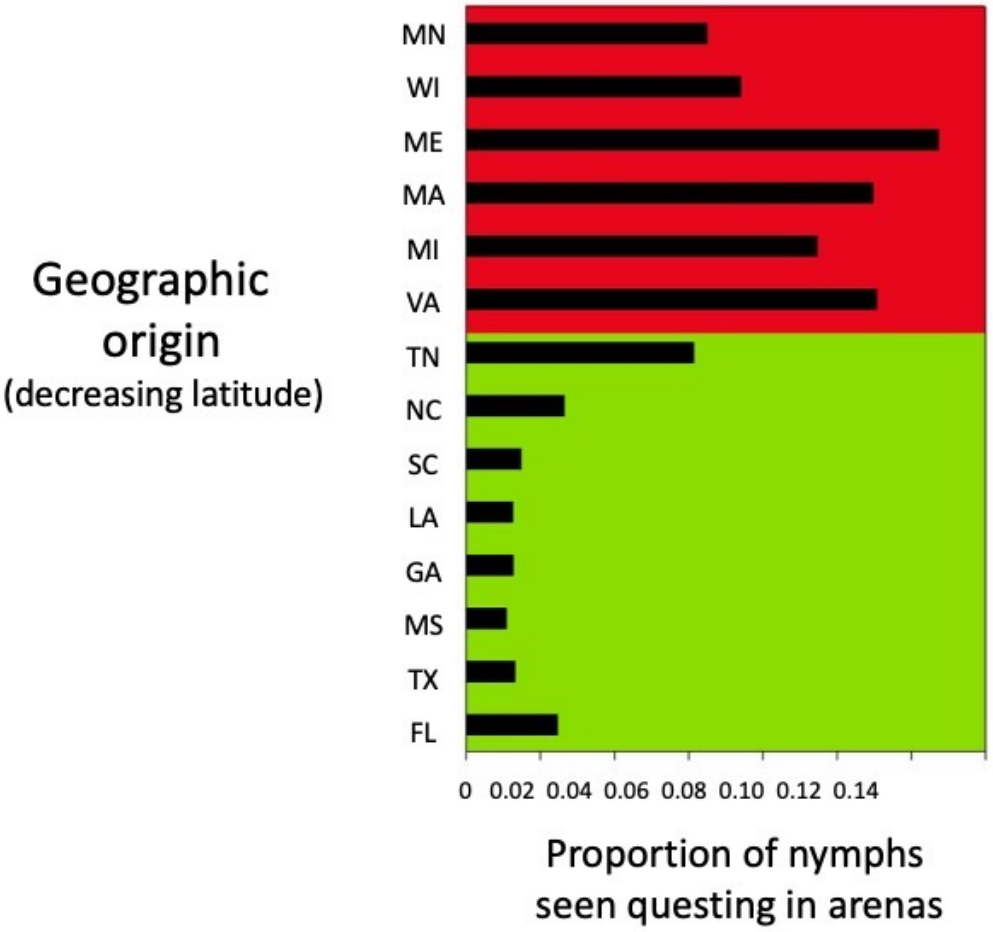
(Eisen et al. 2016)

This implies North–South differences in nymphs' host-seeking behavior



# Scored questing behavior (2 min)

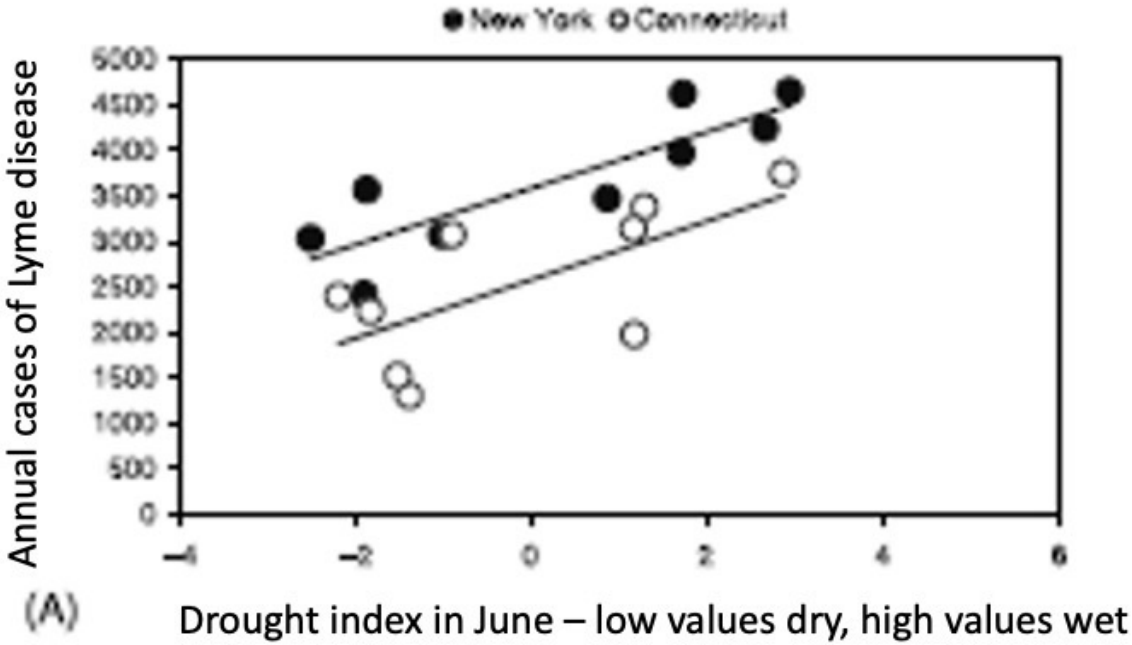
**Results:** Questing behavior of nymphs correlates with pattern of human LD risk




Arsnoe et al. 2019

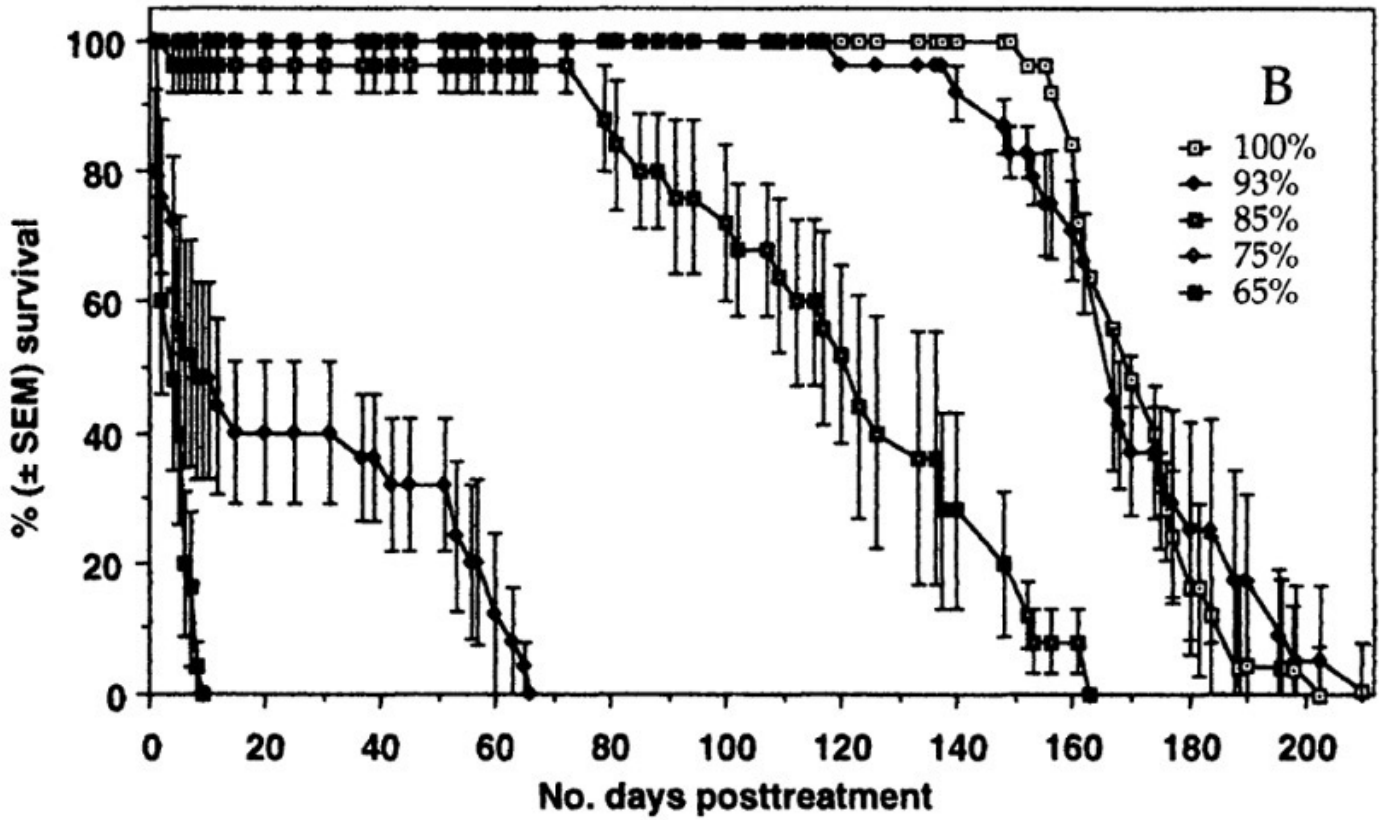
# Environmental factors - Moisture

**Relationship of Lyme disease to environmental moisture**




Subak. 2002. *Exp. Appl. Acarol.* 28:249-256

# Impact of relative humidity on ticks




Stafford. 1994. *J. Med. Entomol.* 31:310-314

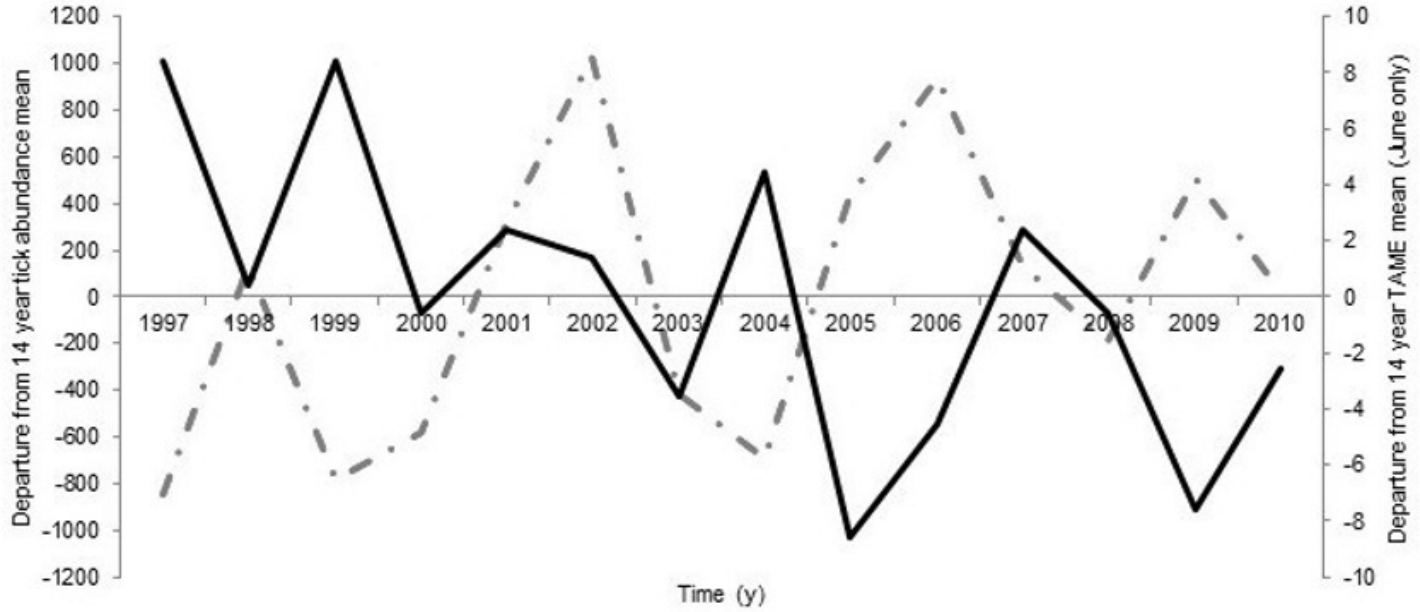
Research | Open Access | Published: 14 April 2014

# Adverse moisture events predict seasonal abundance of Lyme disease vector ticks (*Ixodes scapularis*)

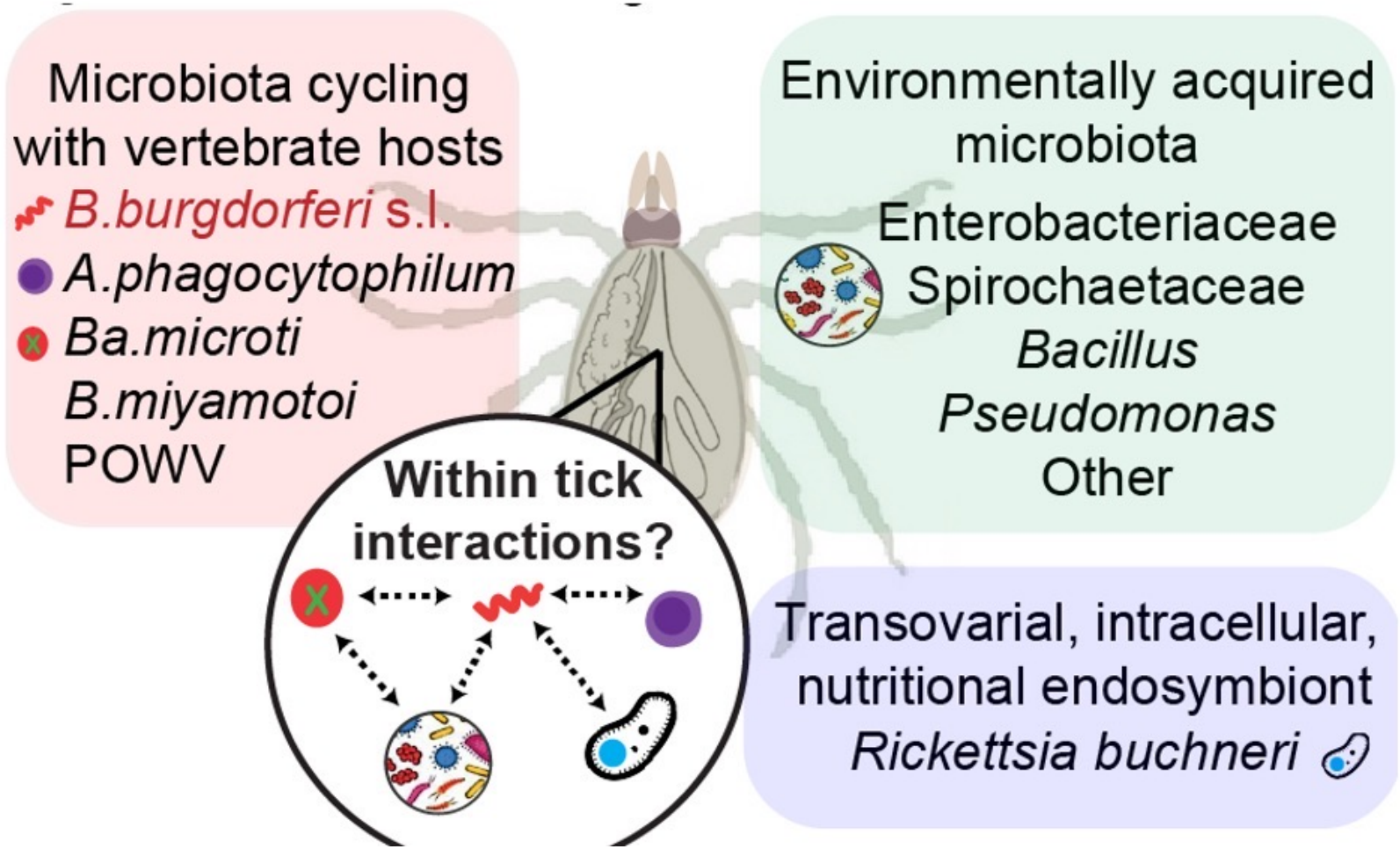
Kathryn A Berger ✉, Howard S Ginsberg, Katherine D Dugas, Lutz H Hamel & Thomas N Mather

*Parasites & Vectors* **7**, Article number: 181 (2014) | Cite this article



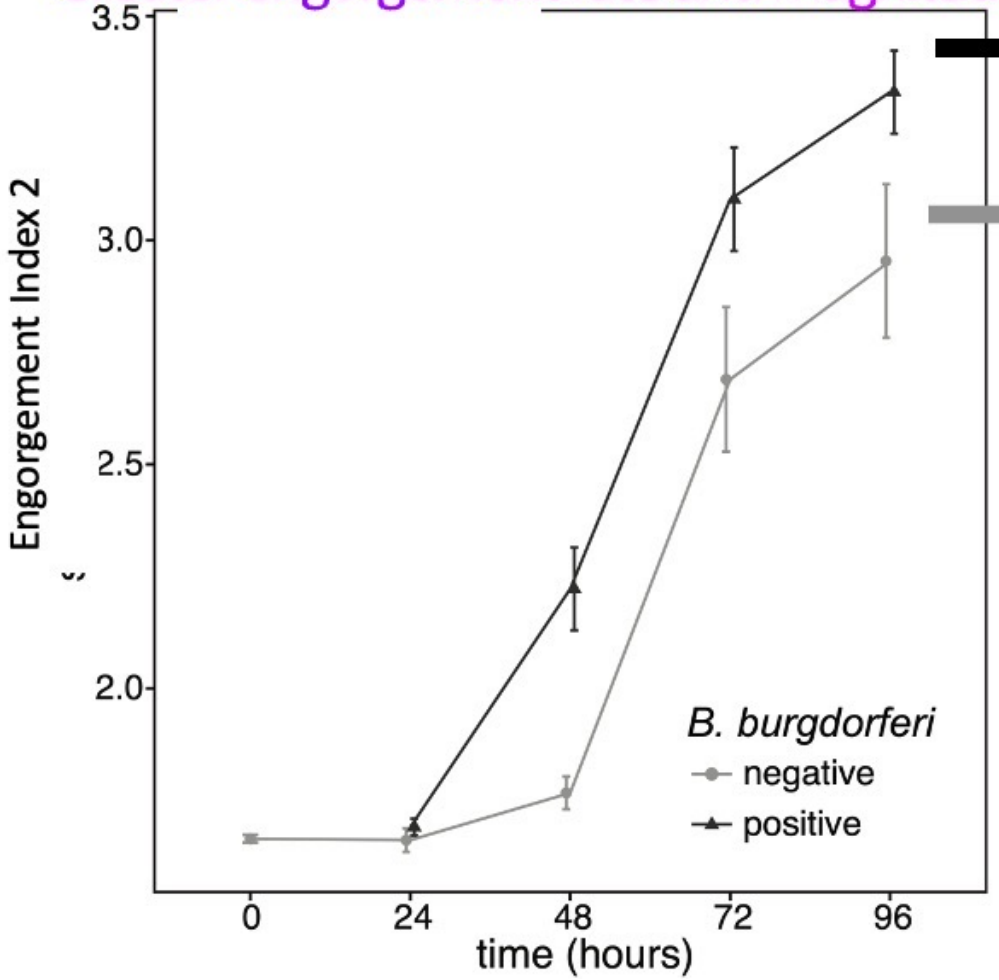


# The Tick Microbiome



# Microbes are actively interacting with ticks...

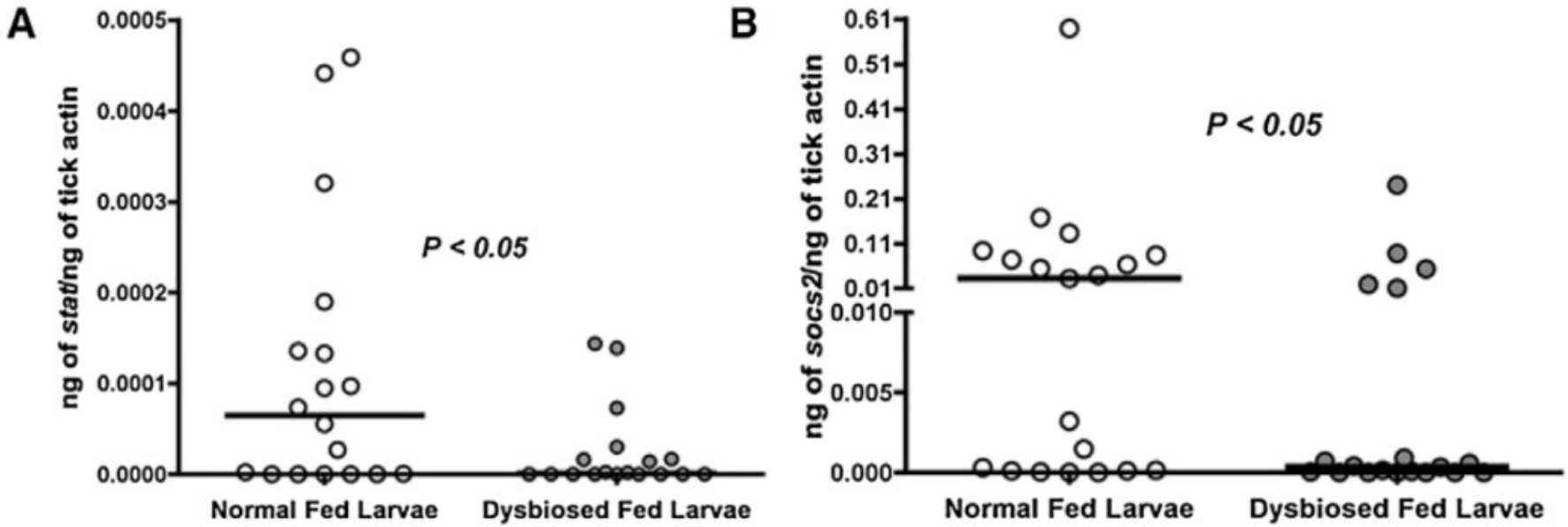
## Greater engorgement rate and magnitude in Borrelia burgdorferi infected ticks




Couret et al. 2017

# And microbes are actively interacting within ticks…

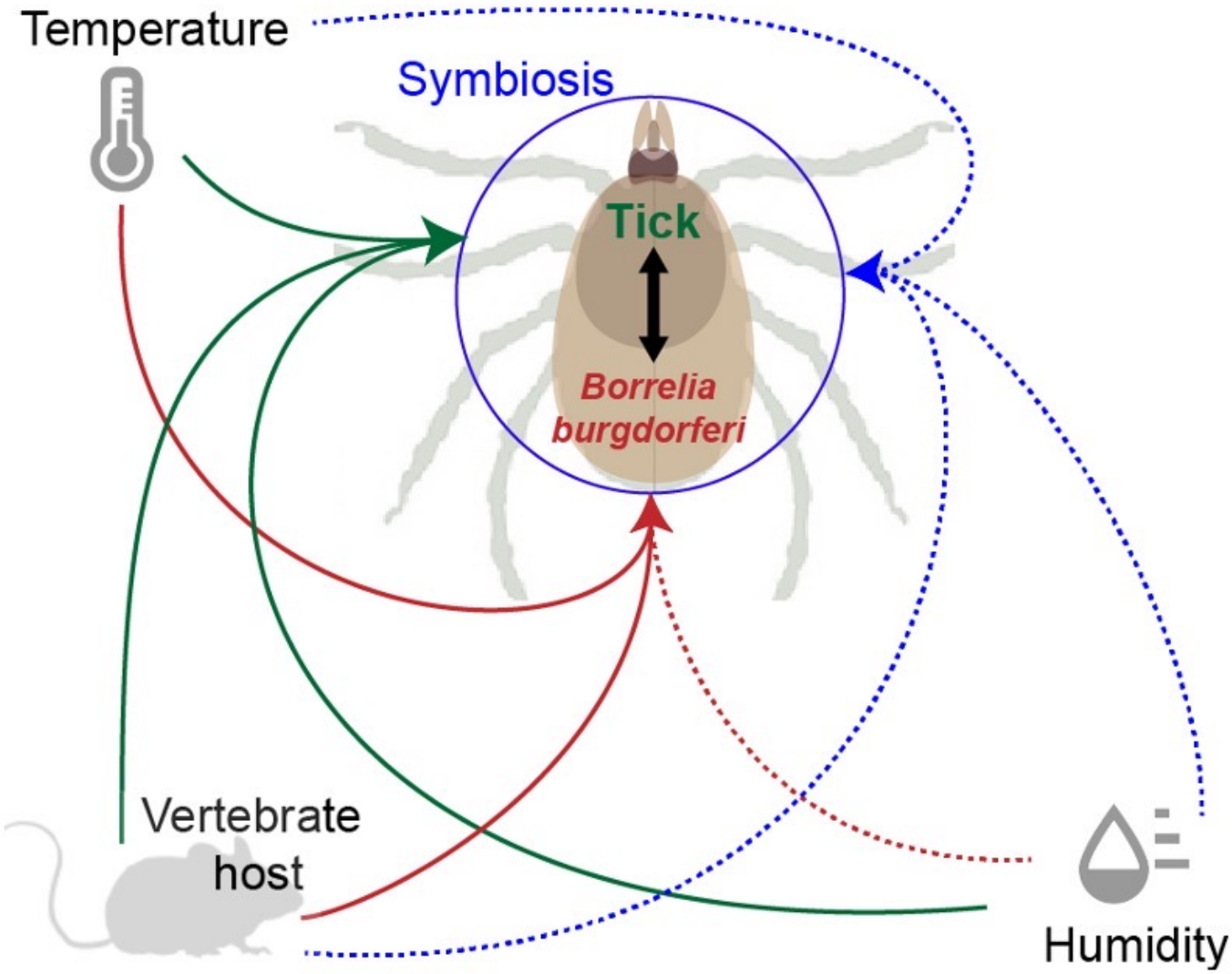
## Gut Microbiota of the Tick Vector *Ixodes scapularis* Modulate Colonization of the Lyme Disease Spirochete




Narasimhan et al. 2014

# It is an ensemble

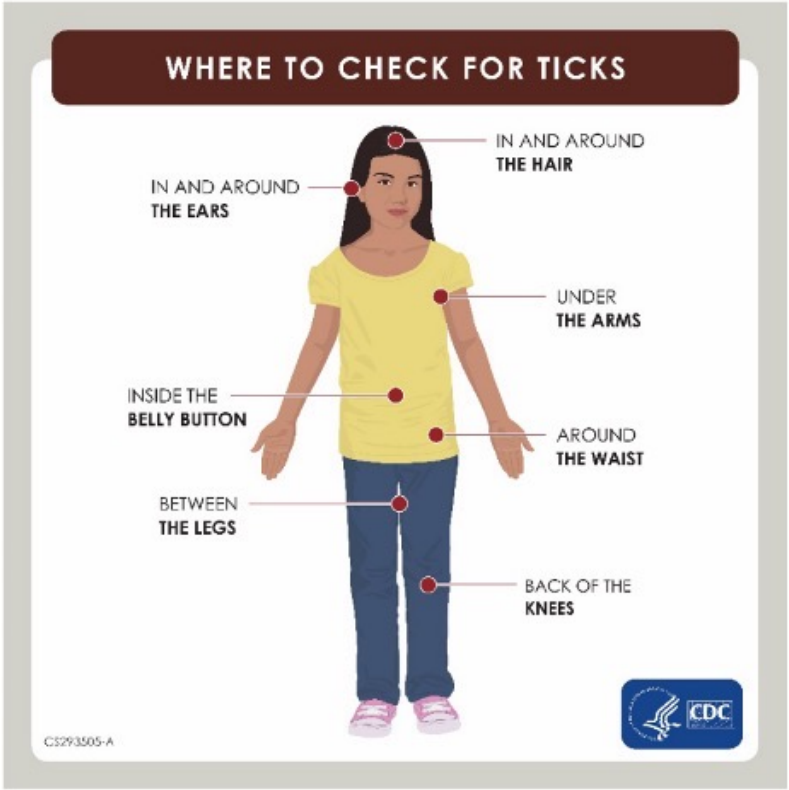
The environment
The tick
The pathogen
The microbiome



# Management of Lyme disease with Structured Decision Making

**The best laid schemes of mice and men often go awry.**
-Robert Burns

# Tick bite prevention remains the best defense for now!



# Prevention method

Evaluation of cost-efficacy

Efficacy = reducing number of blacklegged tick nymphs?

Not necessarily…

Nonlinearities in transmission dynamics and efficient management of vector-borne pathogens

Howard S. Ginsberg [1,3] and Jannelle Couret [2]

[1]U.S. Geological Survey, Patuxent Wildlife Research Center, Rhode Island Field Station, Department of Plant Sciences and Entomology, University of Rhode Island, Kingston, Rhode Island 02881 USA
[2]Department of Biological Sciences, University of Rhode Island, Kingston, Rhode Island 02881 USA

*Citation:* Ginsberg, H. S., and J. Couret. 2019. Nonlinearities in transmission dynamics and efficient management of vector-borne pathogens. Ecological Applications 29(4):e01892. 10.1002/eap.1892

*Abstract.* Integrated Pest Management (IPM) is an approach to minimizing economic and environmental harm caused by pests, and Integrated Vector Management (IVM) uses similar methods to minimize pathogen transmission by vectors. The risk of acquiring a vector-borne infection is often quantified using the density of infected vectors. The relationship between vec-

# Potential non-linearities in tick-borne disease transmission

- Density-dependence of finding

**Effects of tick population dynamics and host densities on the persistence of tick–borne infections**

Roberto Rosà [1], Andrea Pugliese

Affiliations + expand

PMID: 17125804 DOI: 10.1016/j.mbs.2006.10.002

---

- Density-dependent mortality on hosts

Dobson *Parasites & Vectors* 2014, **7**:231
http://www.parasitesandvectors.com/content/7/1/231

*Parasites & Vectors*

RESEARCH Open Access

History and complexity in tick-host dynamics: discrepancies between 'real' and 'visible' tick populations

Andrew D M Dobson

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- Horizontal transmission via co-feeding ticks

Dynamics of a periodic tick-borne disease model with co-feeding and multiple patches

Xue Zhang, Bei Sun & Yijun Lou

*Journal of Mathematical Biology* **82**, Article number: 27 (2021) | Cite this article

**452** Accesses | **2** Citations | Metrics

% control of ticks

(reduction in ERI or DIN)

does not account for non-linearities in pathogen transmission

# Consequence: Relationship of vector numbers to public health protection not linear

## % Control

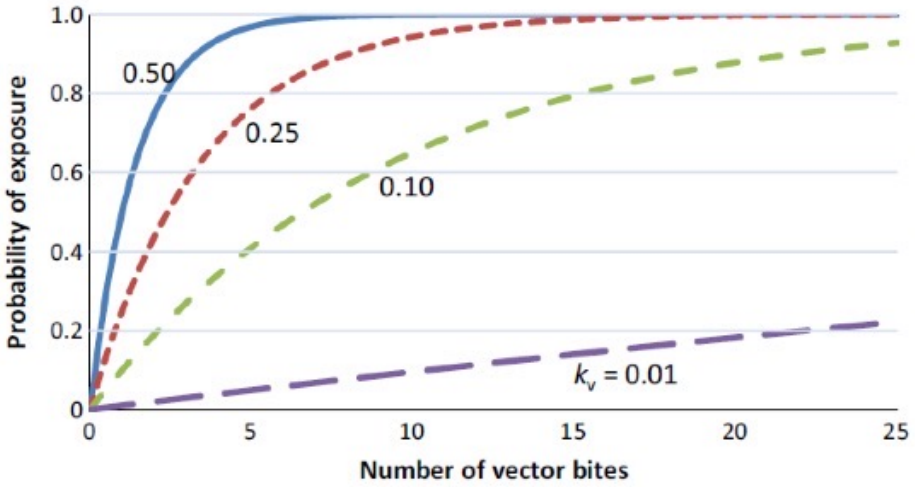
Henderson & Tilton (1955)

**% Control** = 100 x (1 – ($T_a$ x $C_b$)/($T_b$ x $C_a$))

Risk of exposure to a pathogen is not related to the number of vector bites in a linear fashion

Probability of Exposure impacted by

1. Vector infection prevalence
2. Number of vector bites




Probability of Exposure $P_e$

$$P_e = 1 - (1 - k_v)^n$$

# Consequence: Relationship of vector numbers to public health protection not linear

## % Control

Henderson & Tilton (1955)

**% Control** = $100 \times (1 - (T_a \times C_b)/(T_b \times C_a))$

## % Protection

Ginsberg & Couret (2019)

**% Protection** =

$100 \times (1 - (P_{eTa} \times P_{eCb})/(P_{eTb} \times P_{eCa}))$

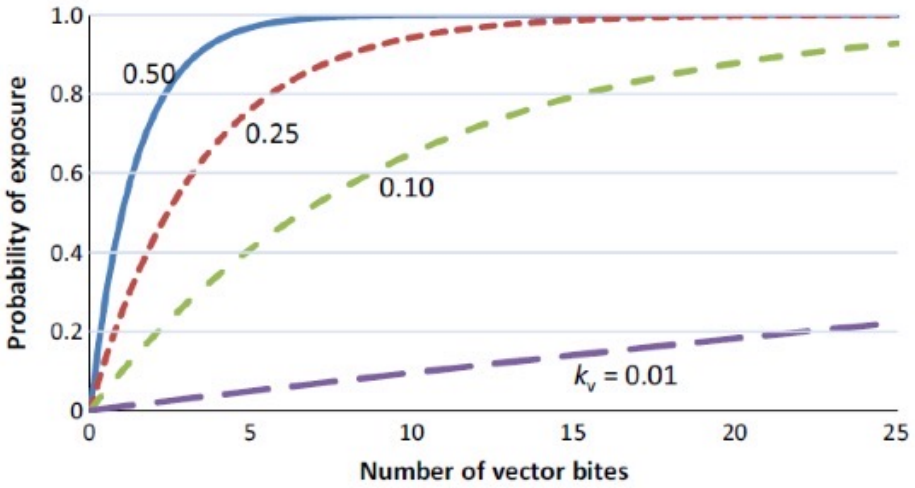
Probability of Exposure $P_e$

$$P_e = 1 - (1 - k_v)^n$$

Risk of exposure to a pathogen is not related to the number of vector bites in a linear fashion

Probability of Exposure impacted by

1. Vector infection prevalence
2. Number of vector bites



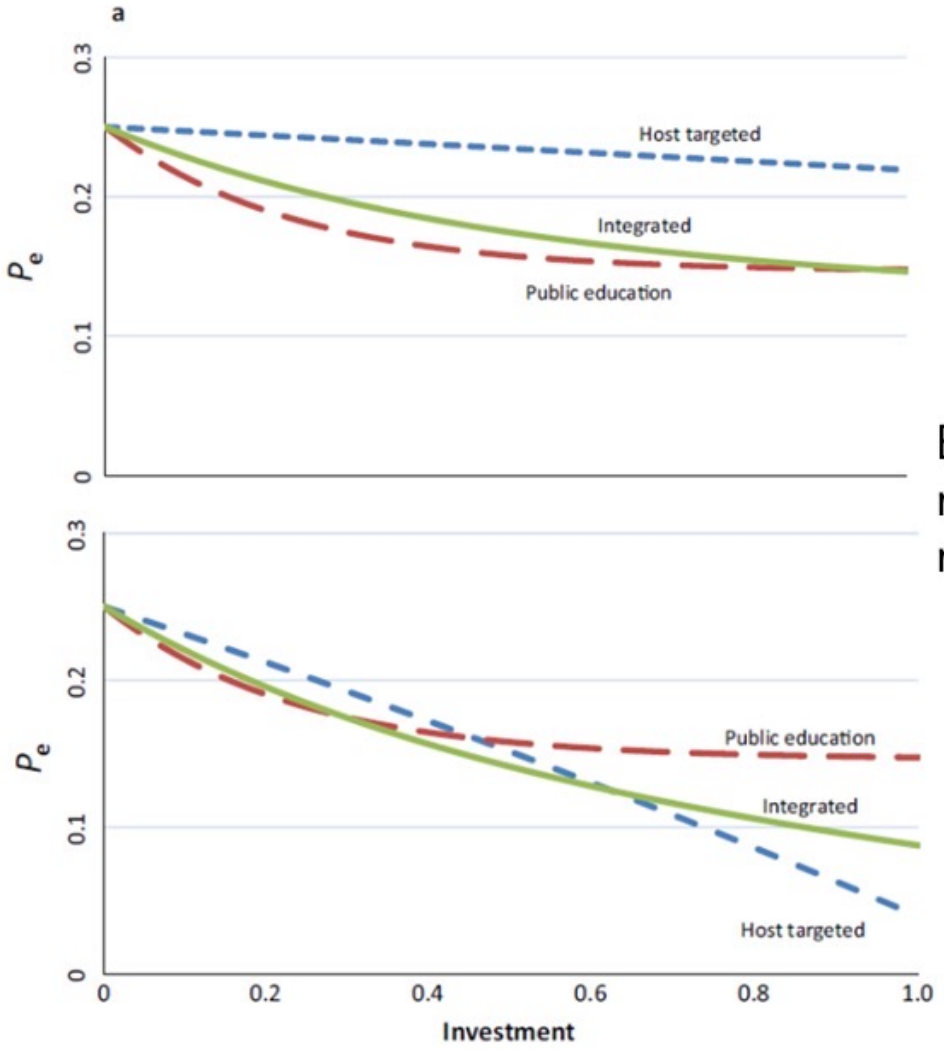
# Efficient and Adaptive Management of Lyme Disease

Scenario 1

Abundant movement White-footed mice into treatment area

Scenario 2

Little movement White-footed mice into treatment area




Efficient integration of management measures (green line)

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| April 12, 2023 | *(South Pacific Teleclass)*<br>**UNINTENDED CONCEQUENCES OF INFECTION PREVENTION AND CONTROL MEASURES DURING THE COVID-19 PANDEMIC**<br>Speaker: **Dr. Moi-Lin Ling**, SingHealth, Singapore |
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