OF MITES & MEN

THE ECOLOGY & MANAGEMENT OF LYME DISEASE

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University of Rhode Island

Vector-borne Disease Ecology & Control

@VEClab

@vectorecology

TickEncounter
THE UNIVERSITY OF RHODE ISLAND

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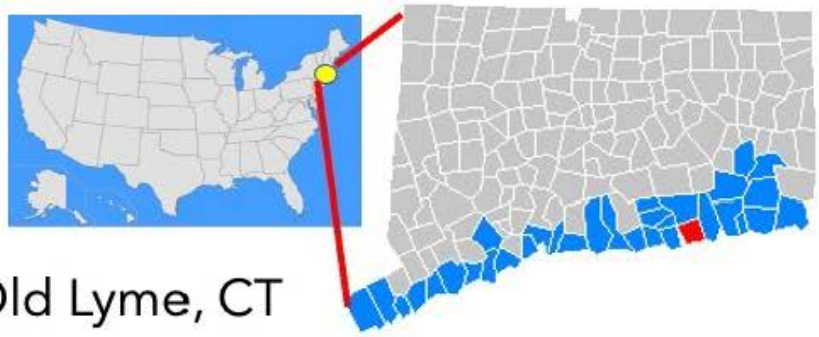
COLLEGE OF THE ENVIRONMENT AND LIFE SCIENCES

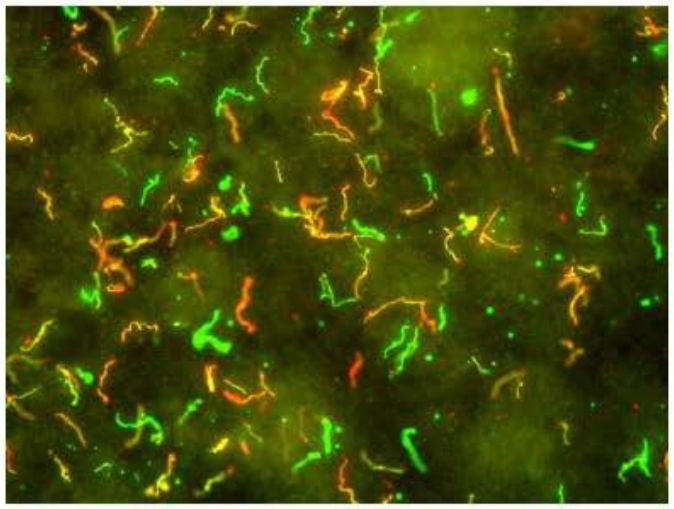
NEWVEC
NEW ENGLAND CENTER OF EXCELLENCE IN VECTOR-BORNE DISEASES

The discovery of Lyme disease in the US 1970s



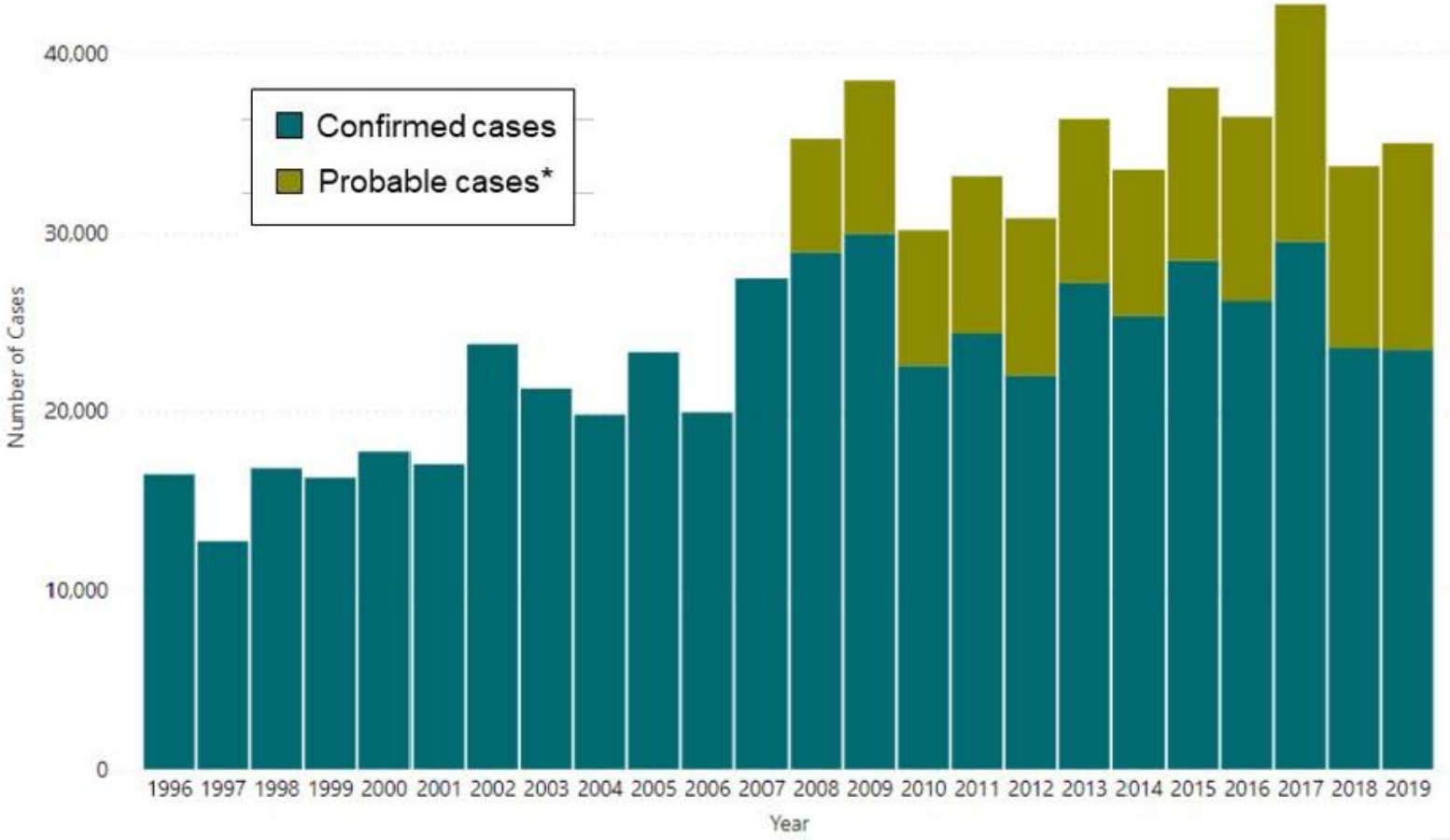
Old Lyme, CT

Borrelia burgdorferi

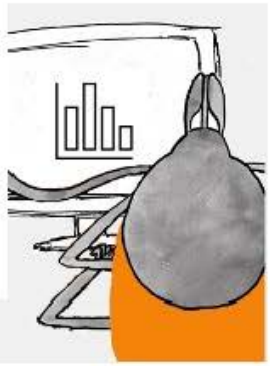


Lyme disease continues to emerge

Lyme disease is emerging over time…



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

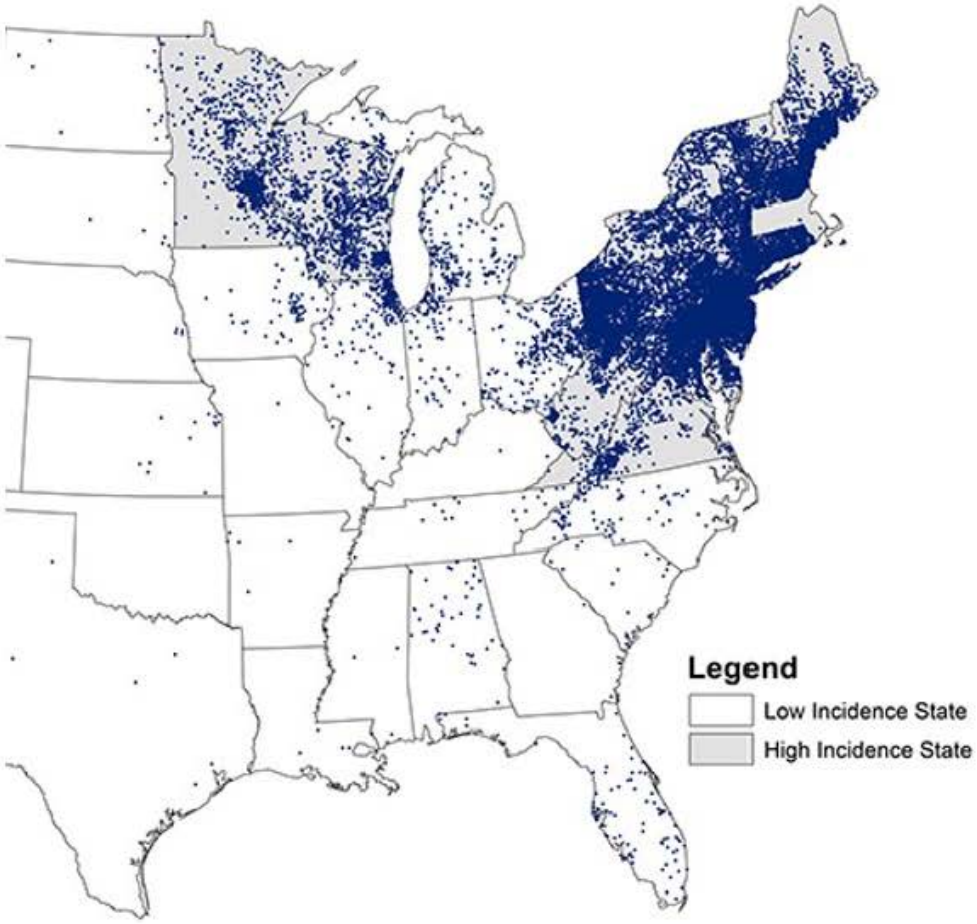


Lyme disease is emerging over space

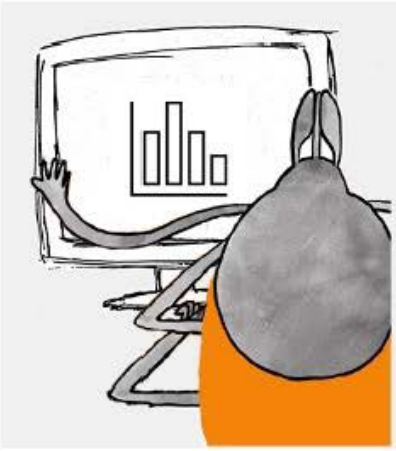
>90% cases occur in 7 northern eastern US

1999

2019

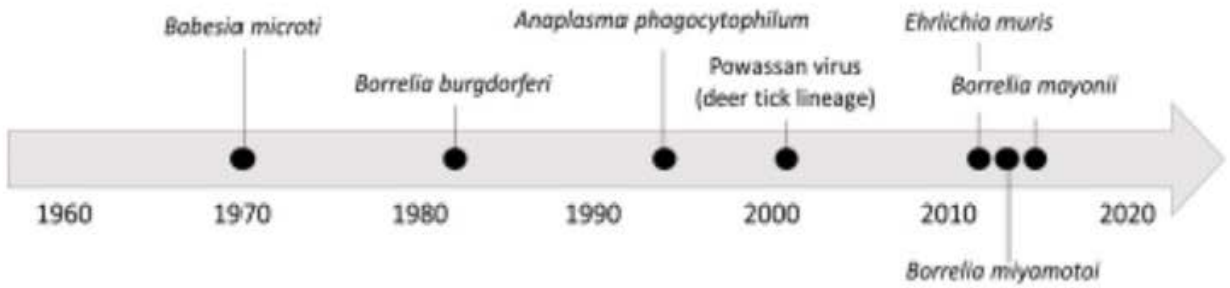


476,000 Americans are diagnosed and treated annually for Lyme disease



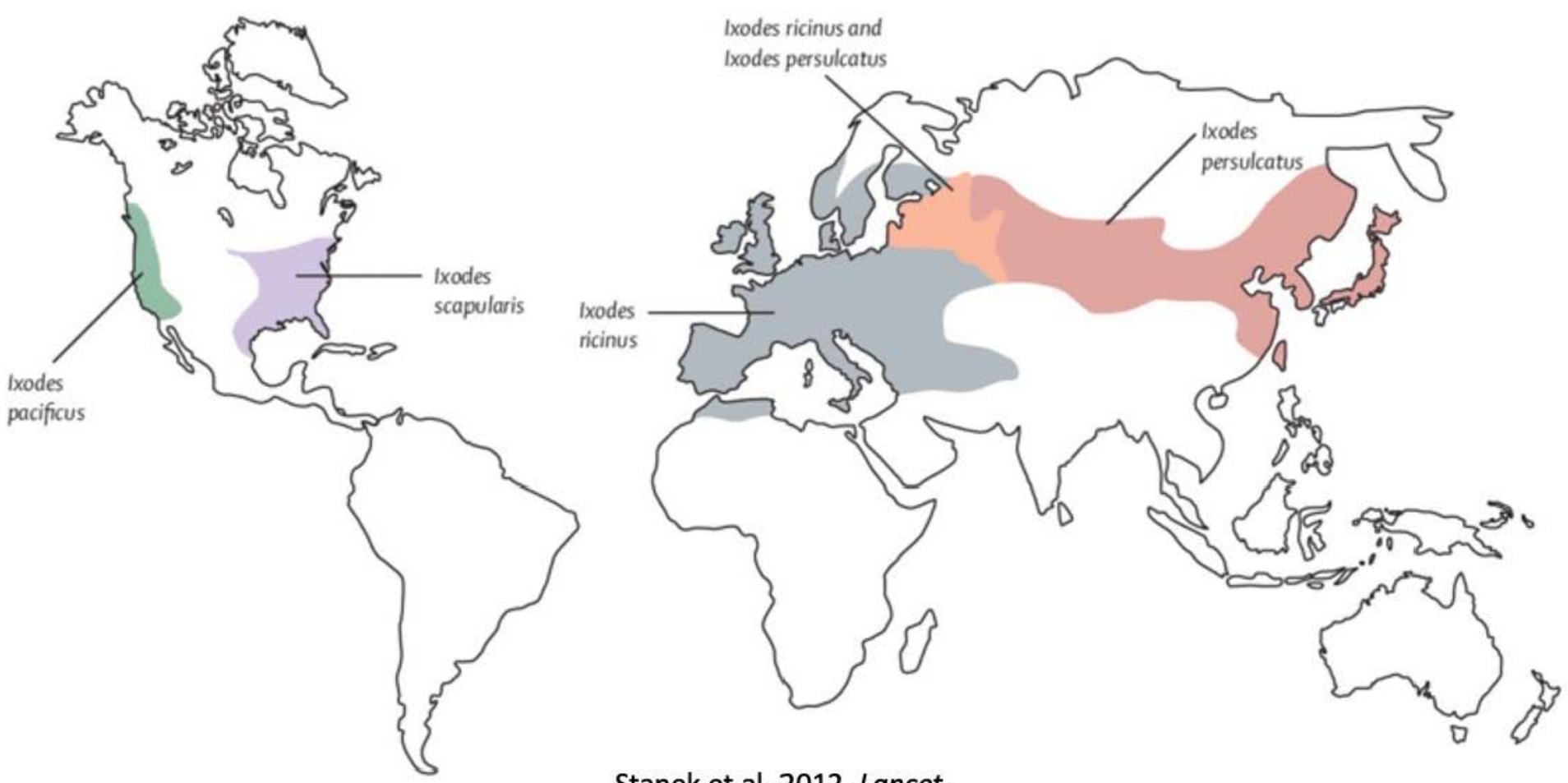
Kugeler et al. 2021
Schwartz et al. 2021

Ixodes scapularis: an increasing public health concern



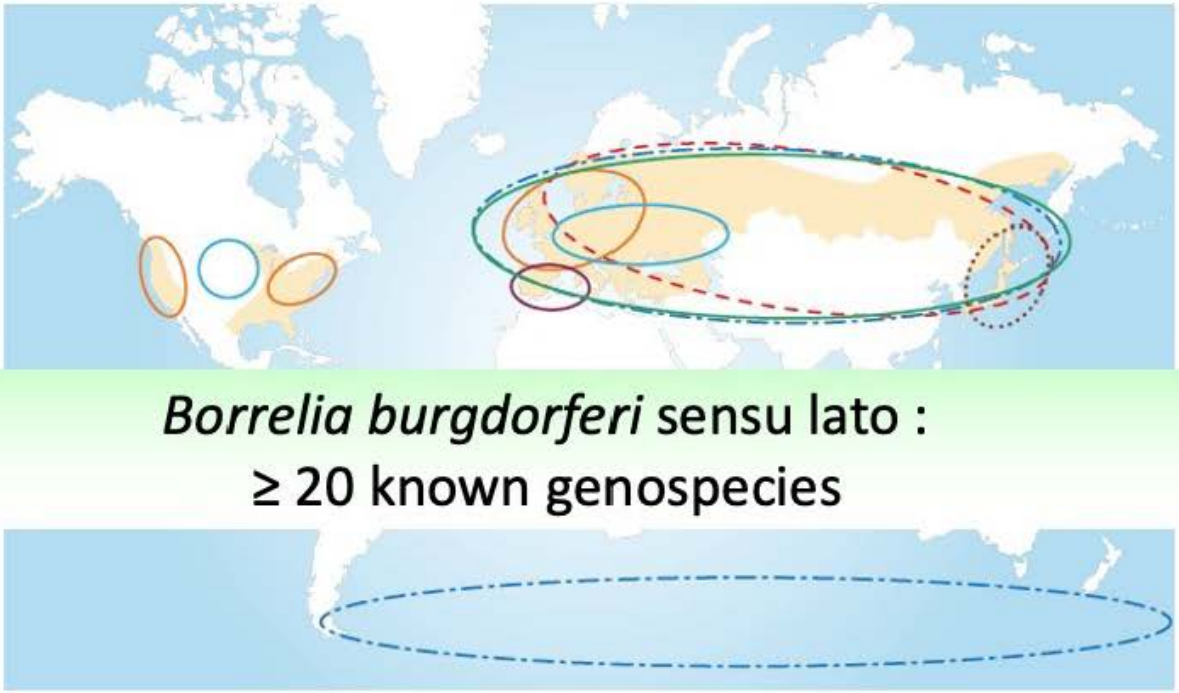
Eisen, RJ and Eisen, L. Trends in Parasitology, 2018. 34:295-309.

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

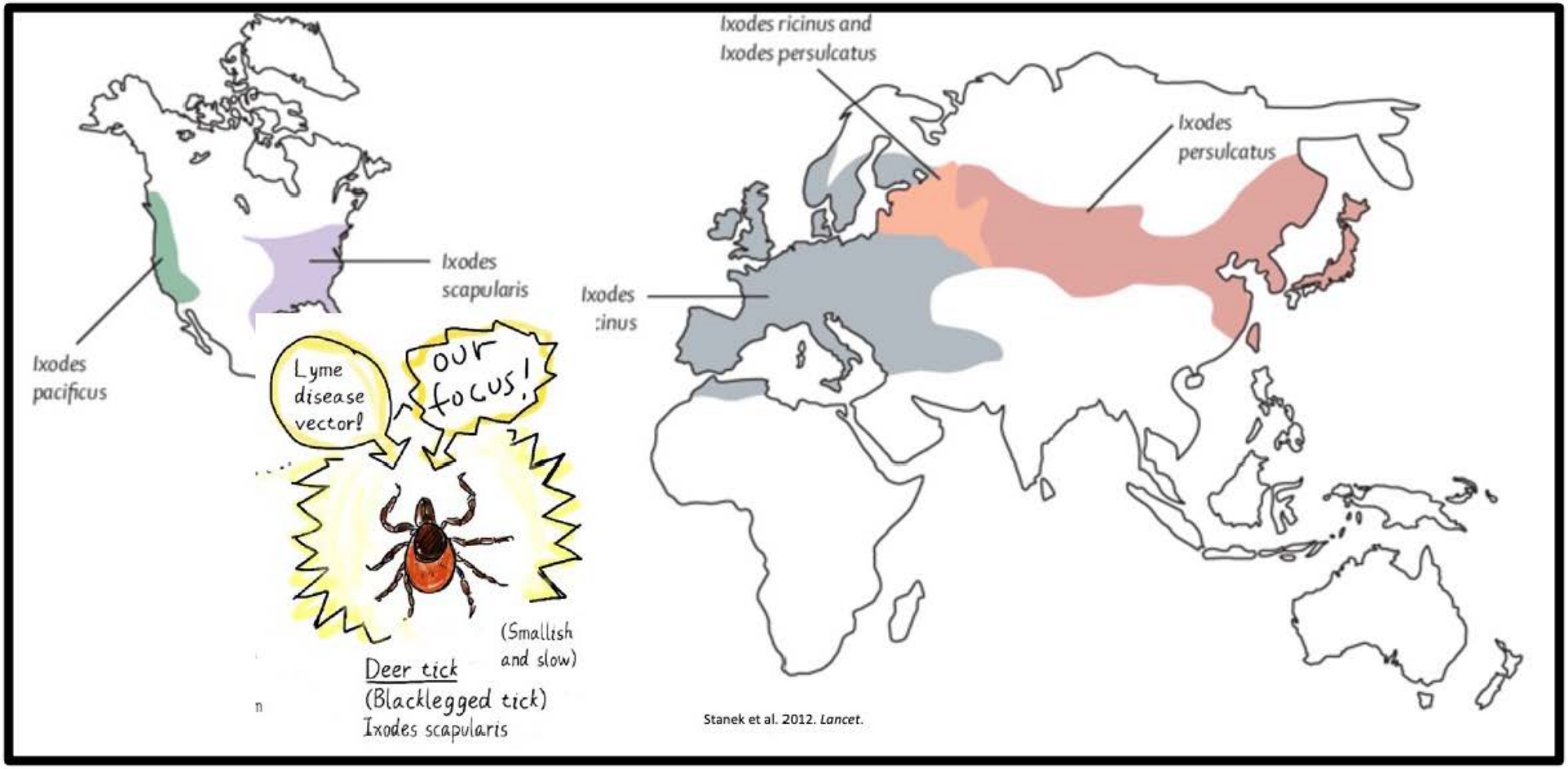


Borrelia burgdorferi **sensu lato :**
≥ 20 known genospecies

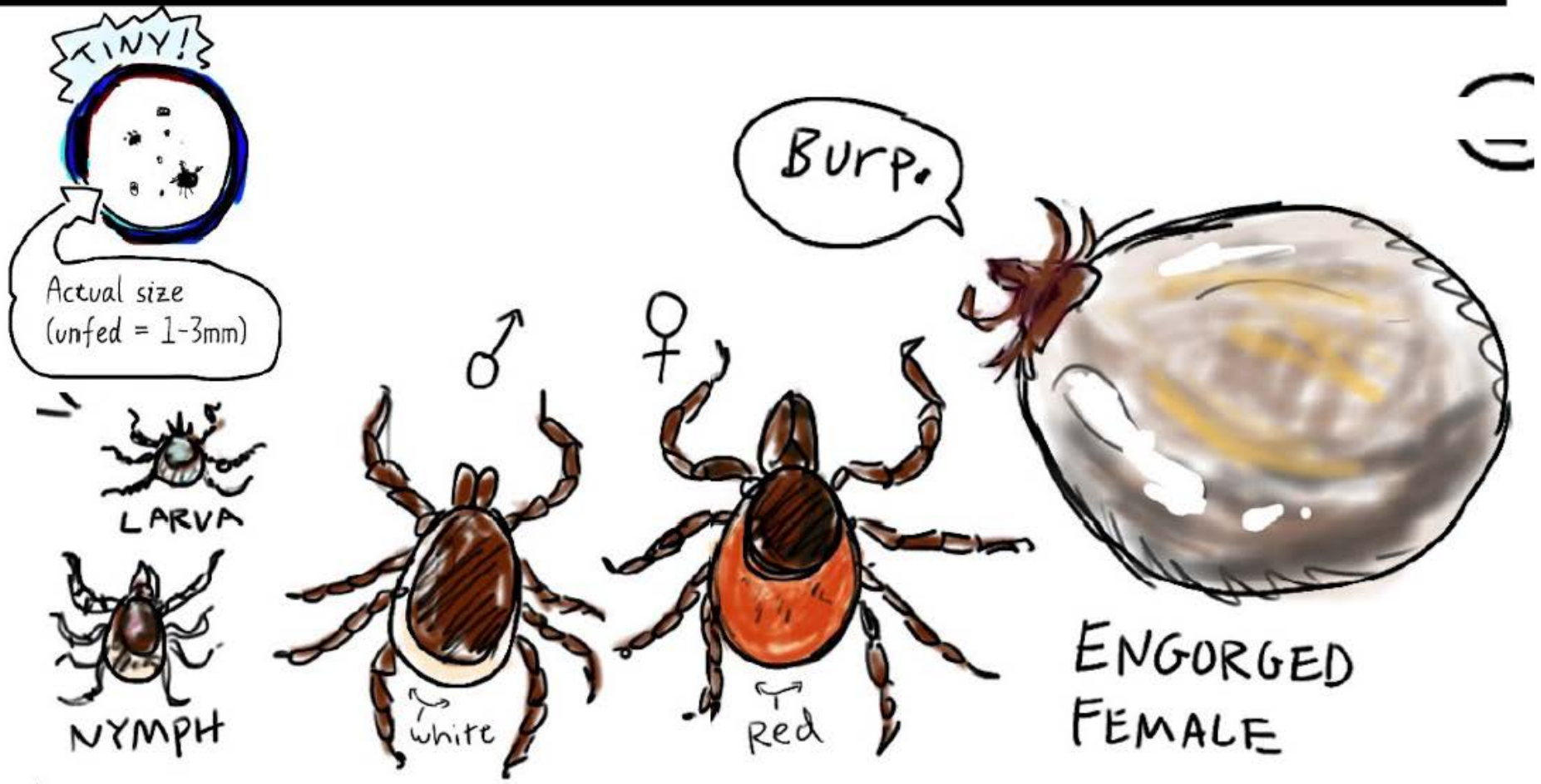
Kurtenbach et al. 2006. *Nature reviews*.

Maintenance of LB enzootic cycles in nature

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

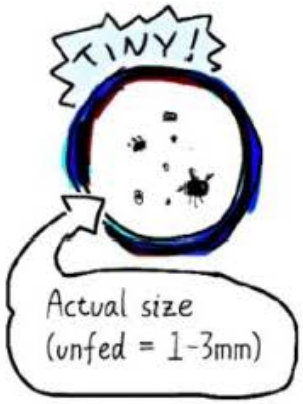


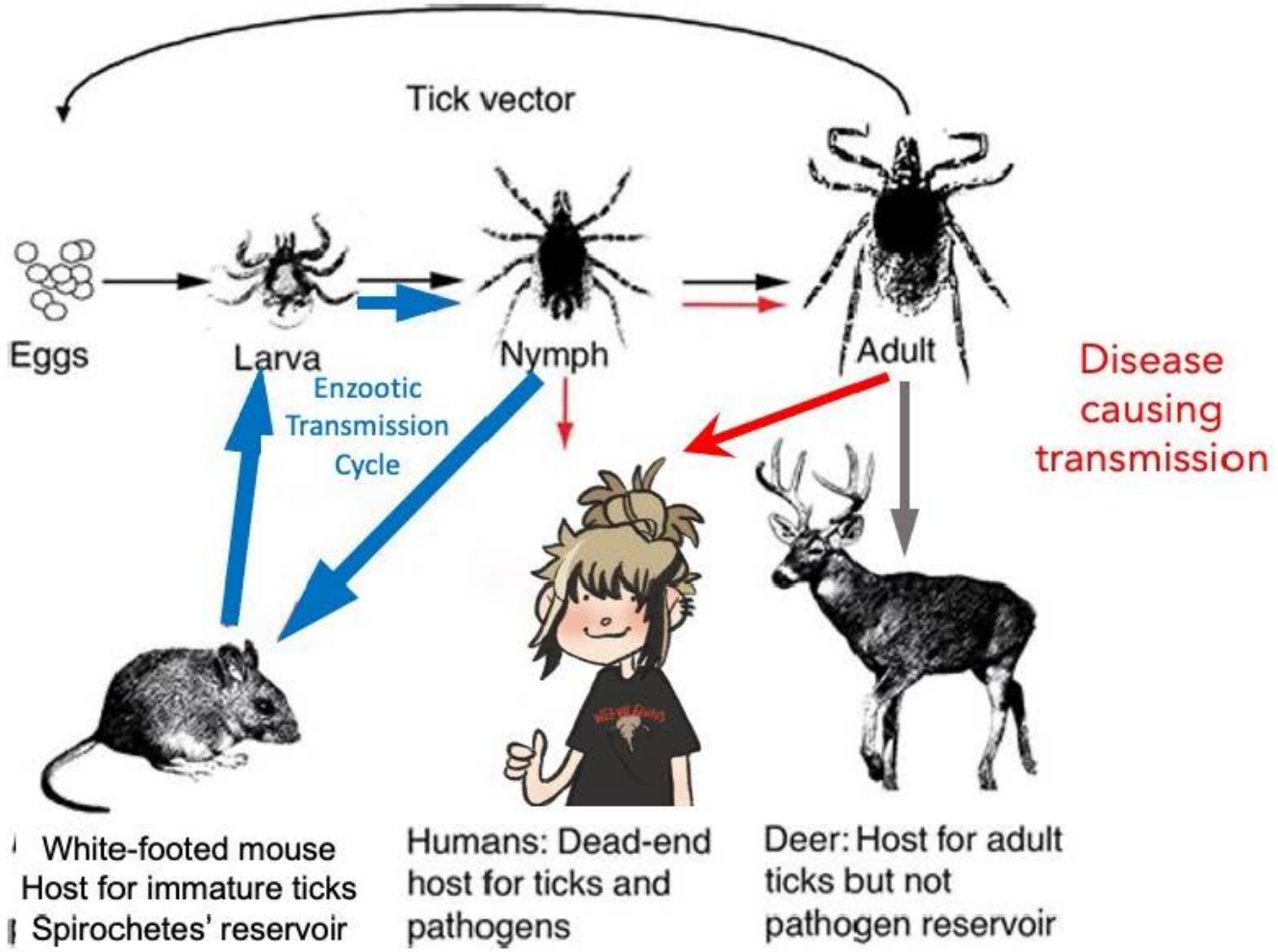
Require a blood meal to develop and reproduce (females)



Females lay eggs in one batch & then die

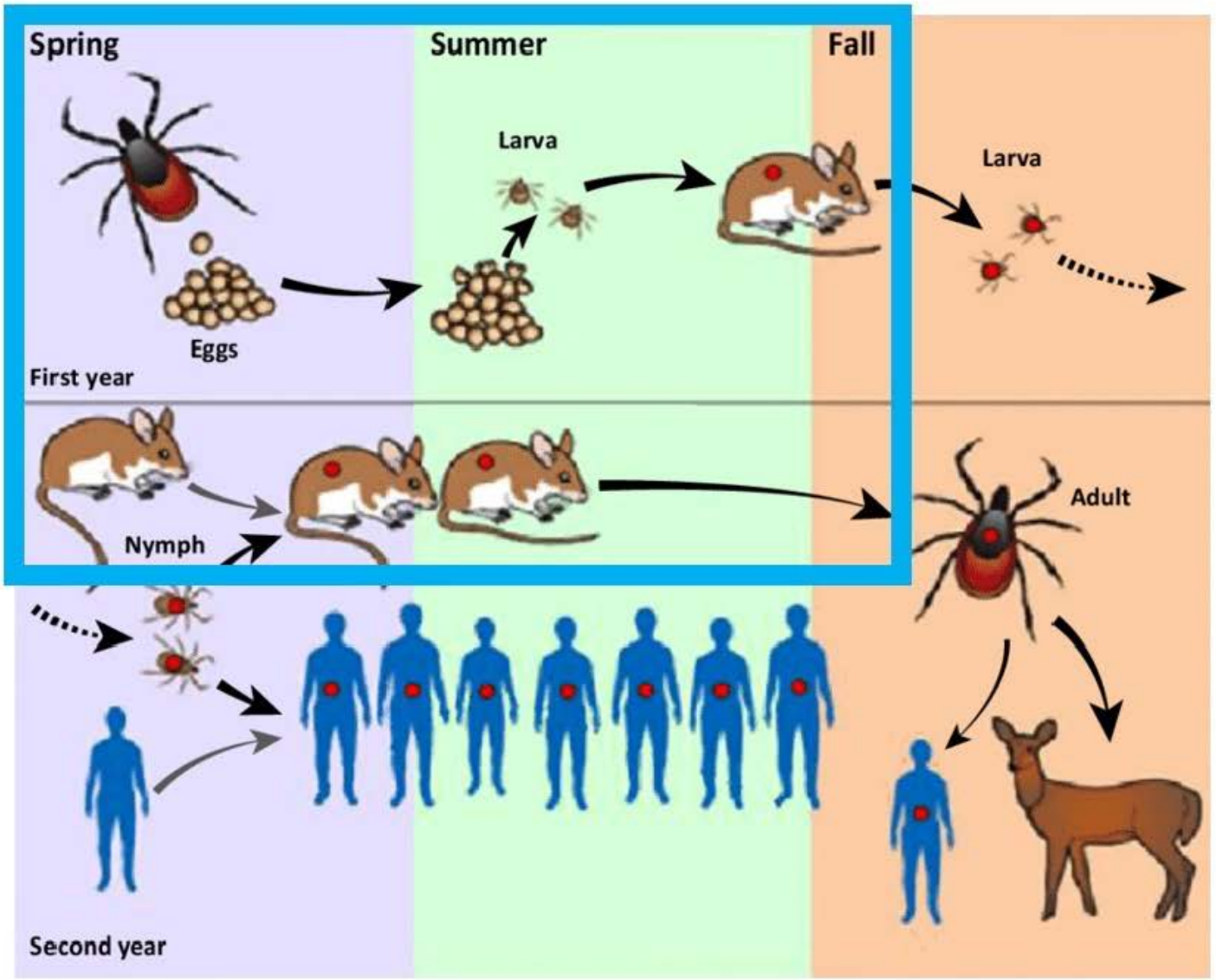
Enzootic vs Spillover Transmission of Lyme spirochetes





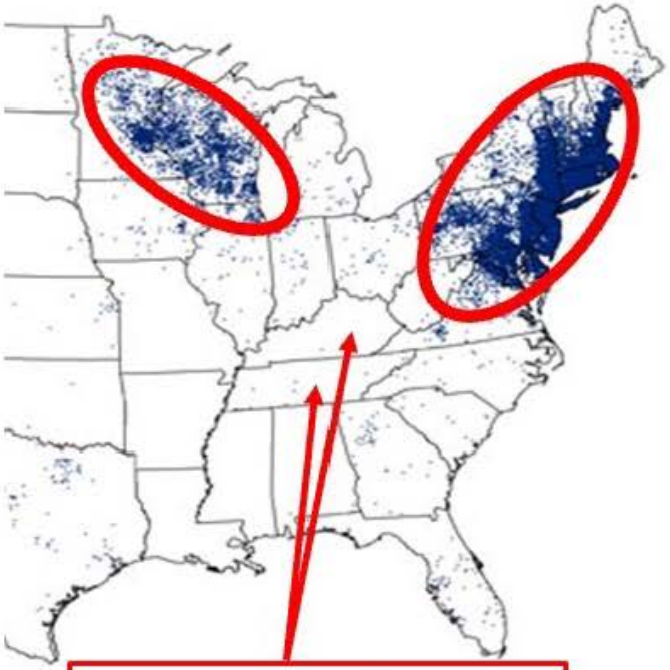
Primary enzootic
Transmission cycle

Maintains
B. burgdorferi

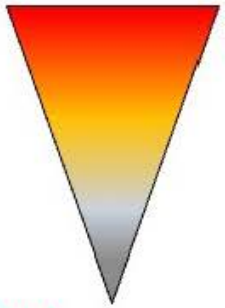


Duik-
Wasser
et al. 2015

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



40 per 100,000



0.4 per 100,000

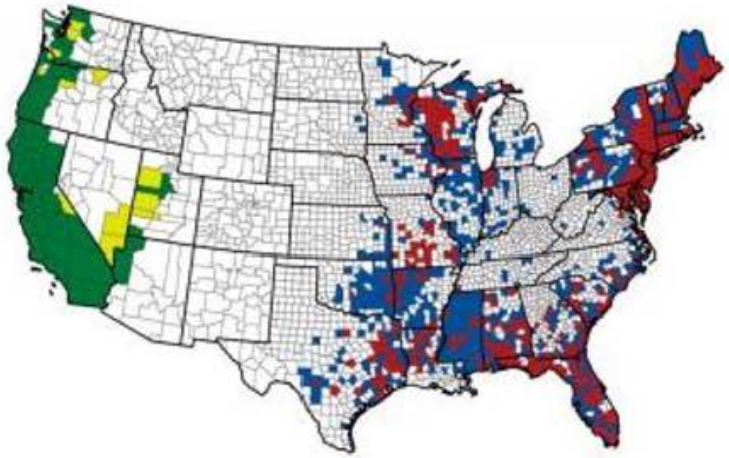
2006 - 2015

KY: avg. 8 cases/yr
TN: avg. 10 cases/yr

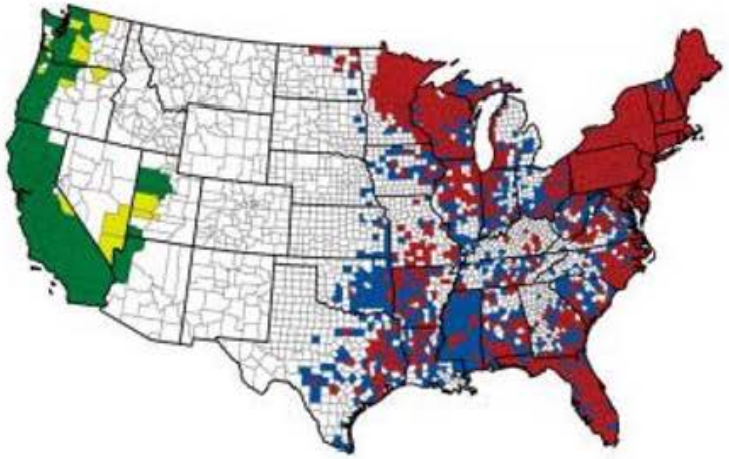
There is a mismatch between human disease and vector-tick distribution

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)

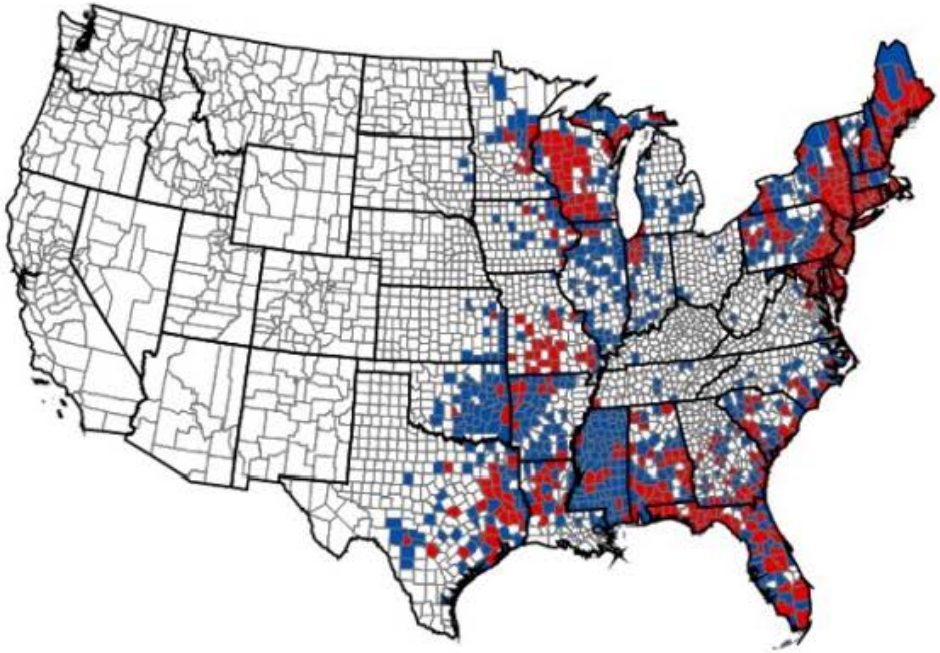


1907-2015 (Eisen et al. 2016)

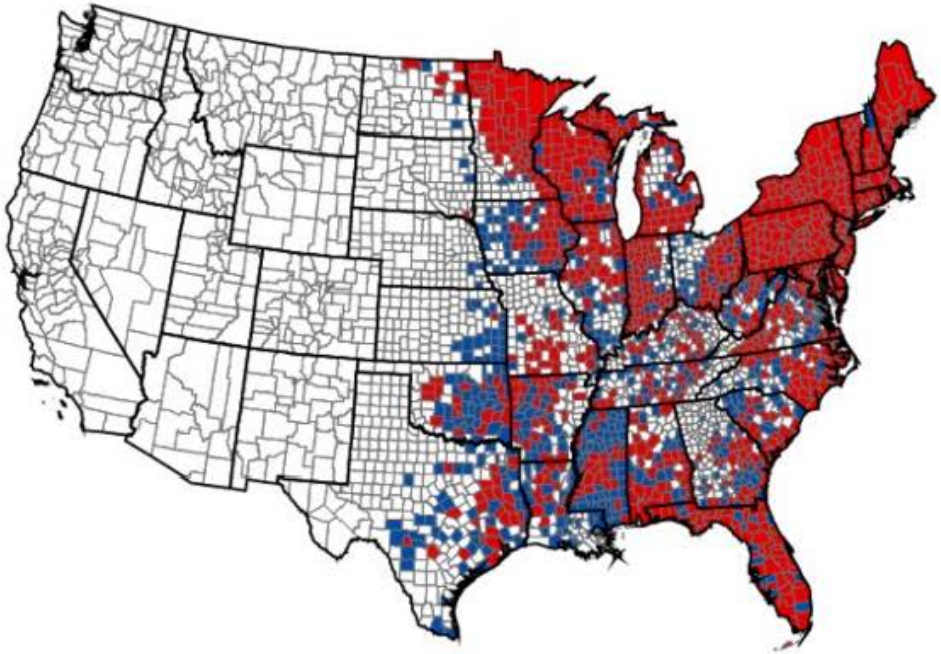
<u>Established</u> tick populations:
≥ 6 ticks or 2 life stages in a single year

Reported Distribution of *I. scapularis* has expanded

1996



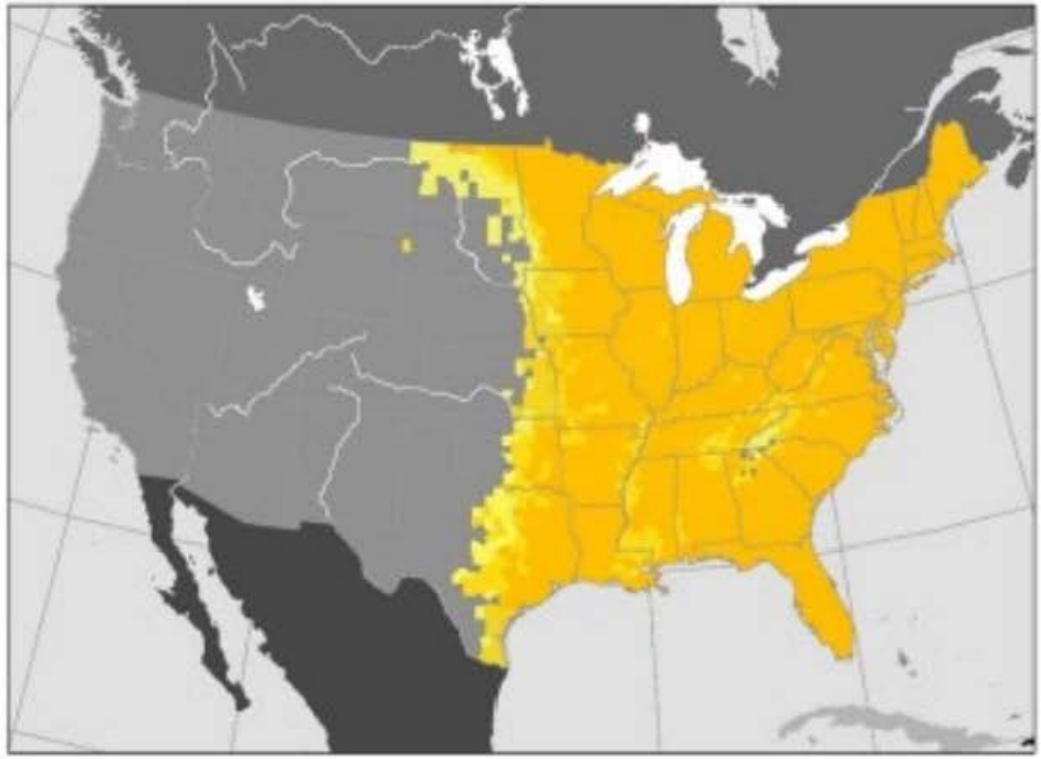
2021



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

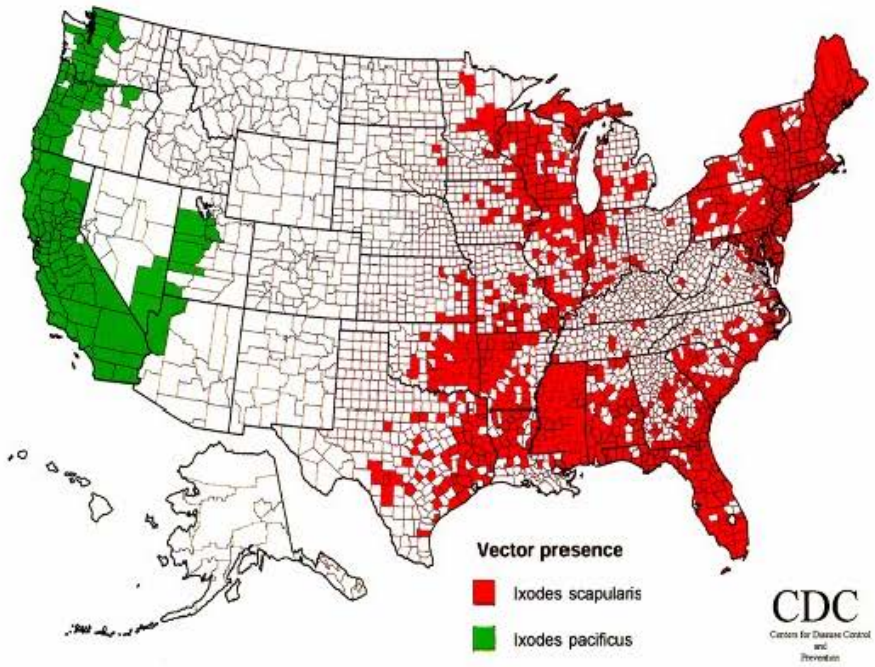
Distribution of suitable habitat, *Ixodes scapularis*

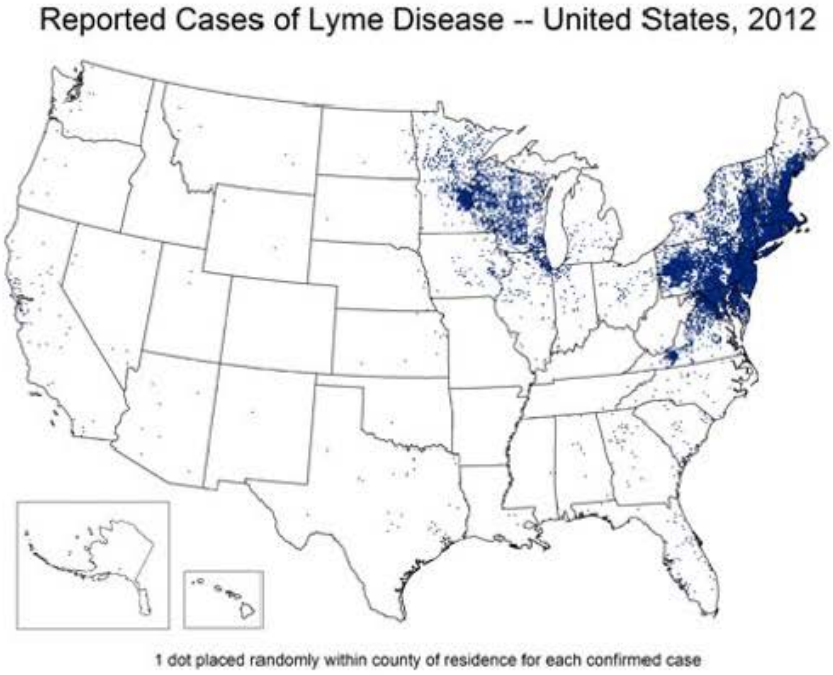


Hahn MB et al. J Med Entomol 2017;54:1104-1106.

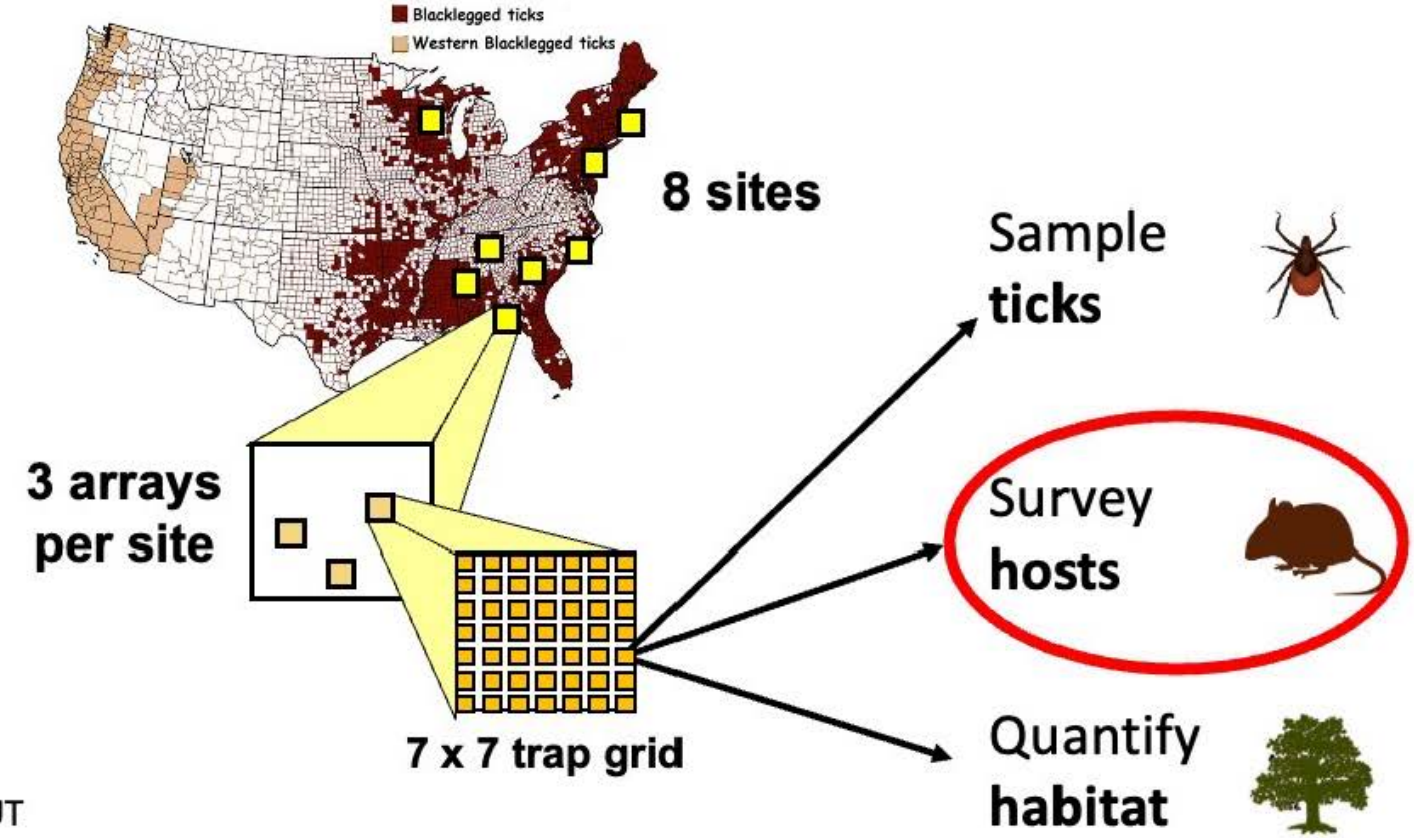
Established: Six or more ticks or more than one life stage recorded in a single year

Tick distribution vs. Human cases





Lyme Gradient Project 2010-2015



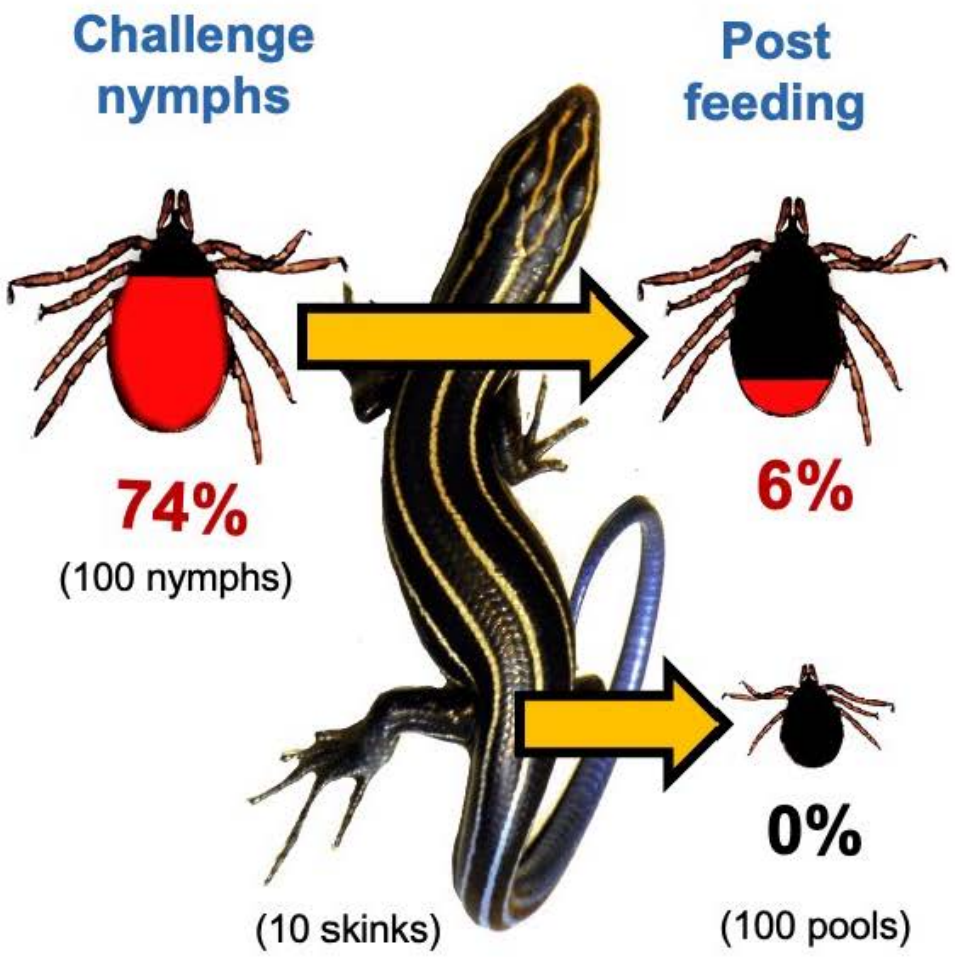
Jean Tsao MSU
Graham Hickling, UT
Howie Ginsberg, URI

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

Northeastern US

Peromyscus leucopus

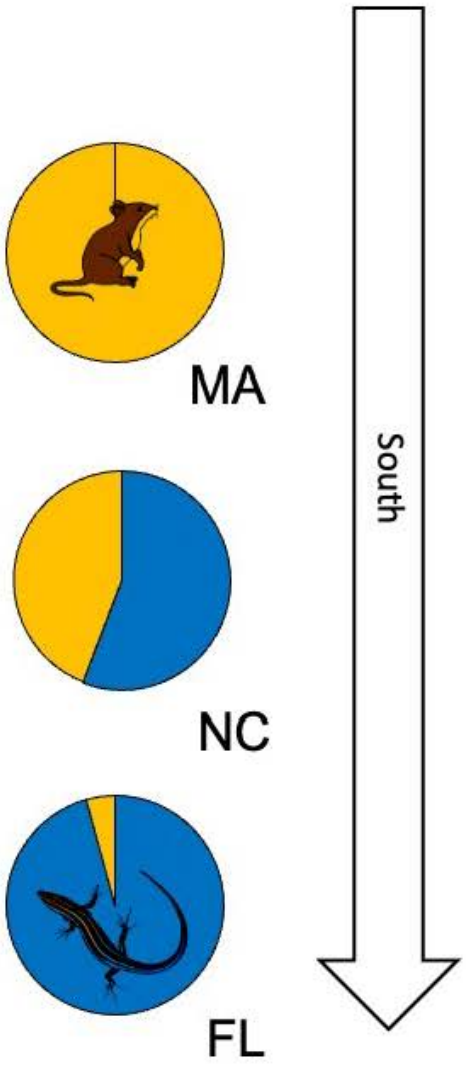
White-footed mouse



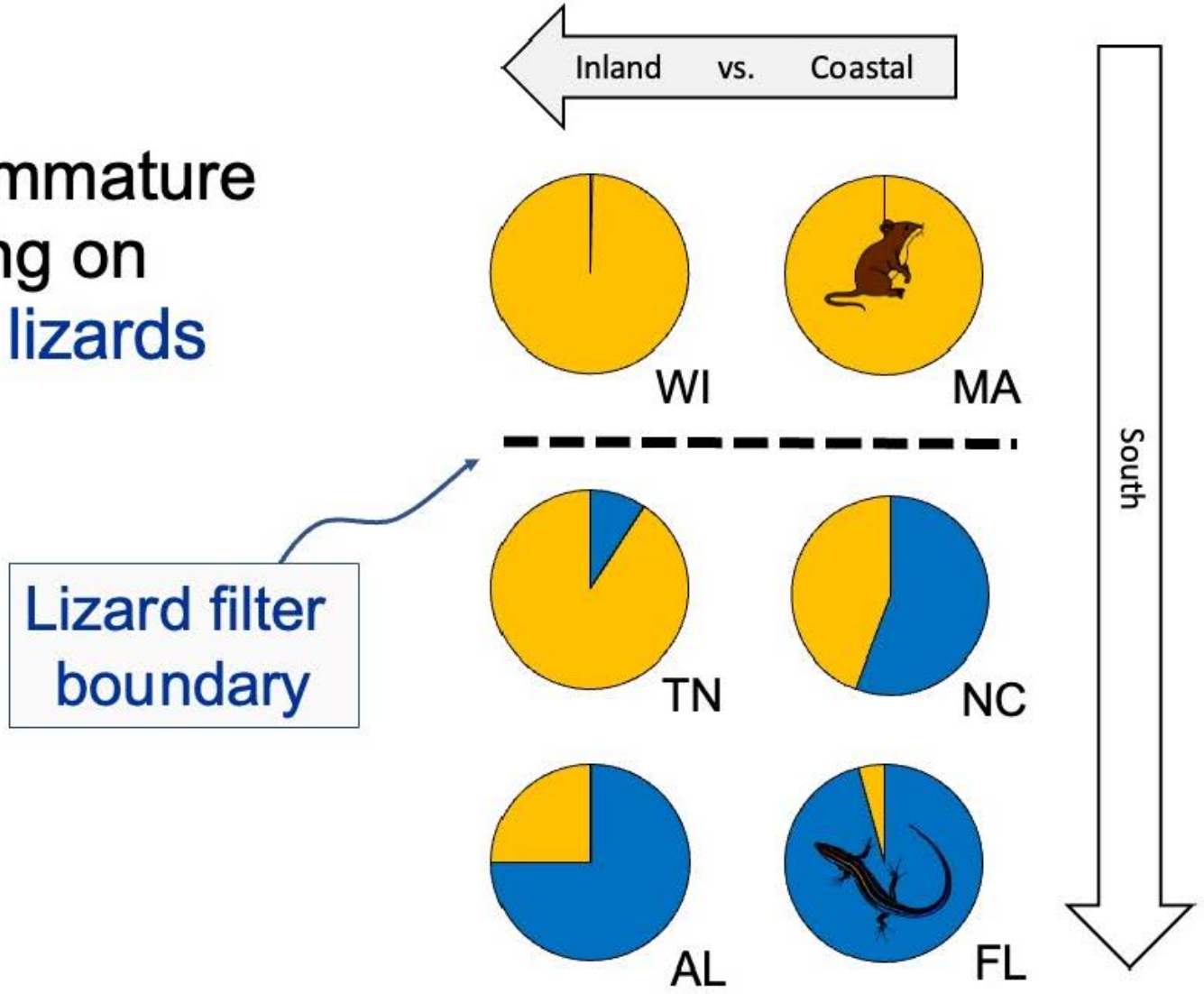
(Nymphs feeding on control mice remained infected)

(100% of control mice produced infected larvae)

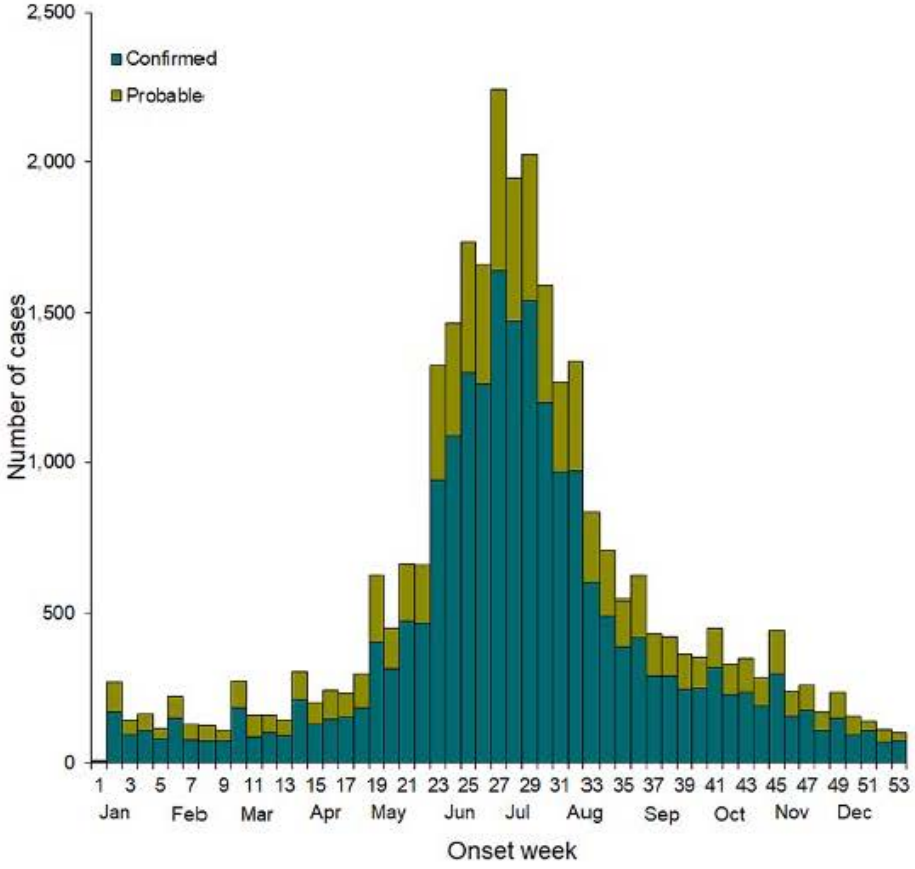
Propn. of immature *Ixodes* feeding on rodents *vs* lizards



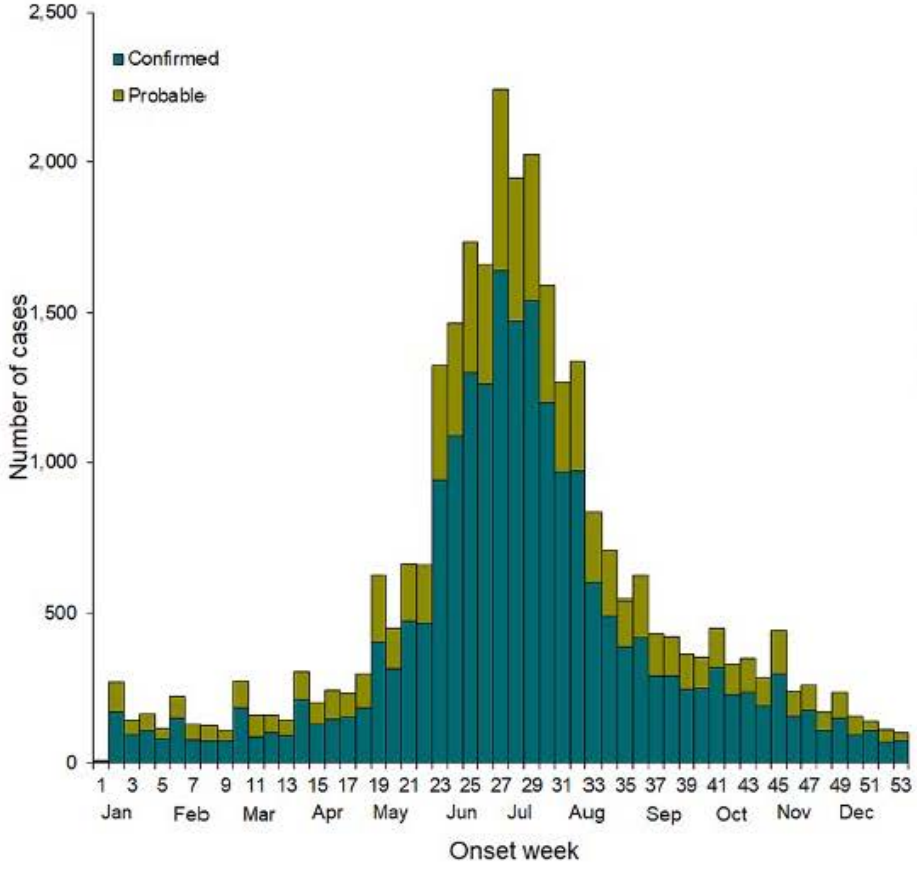
Propn. of immature ticks feeding on rodents *vs* lizards



Lyme disease cases peak in mid summer

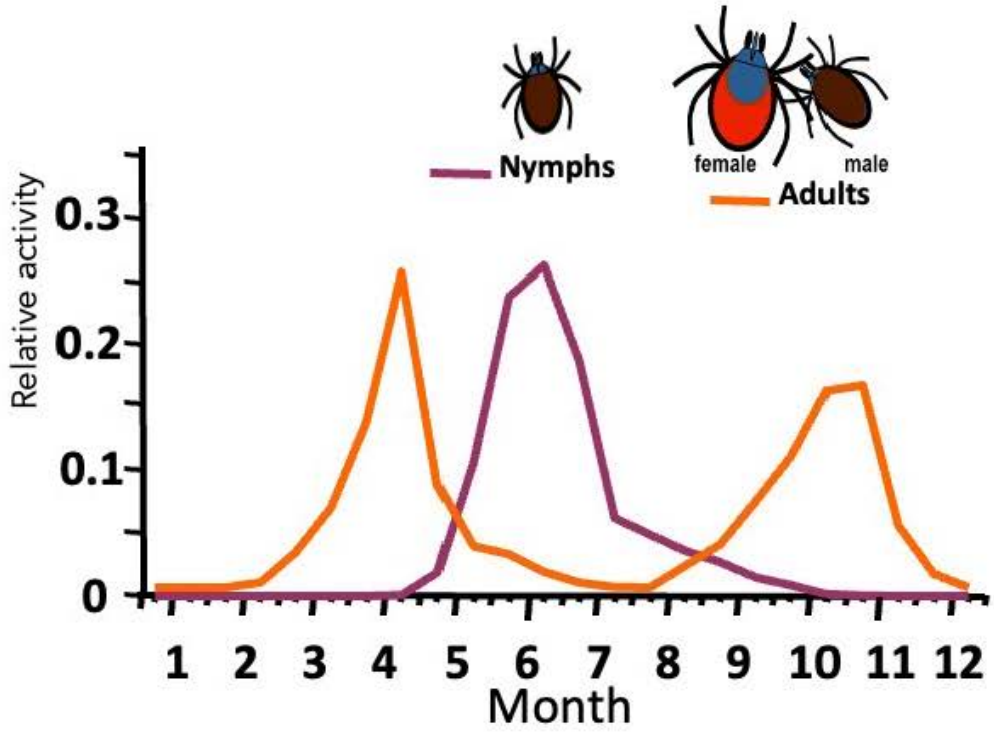


Cdc,.gov



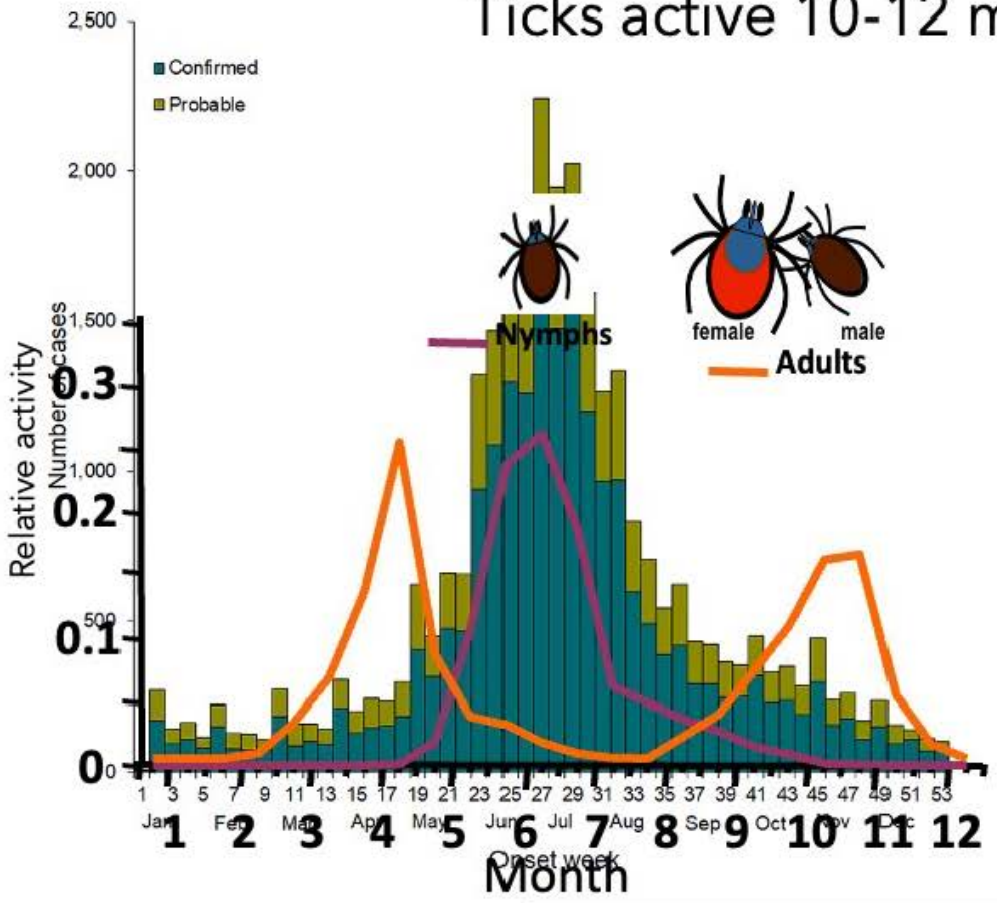
Cdc,.gov

Ticks active 10-12 months of the year



Disease peak coincides with nymphal deer tick abundance

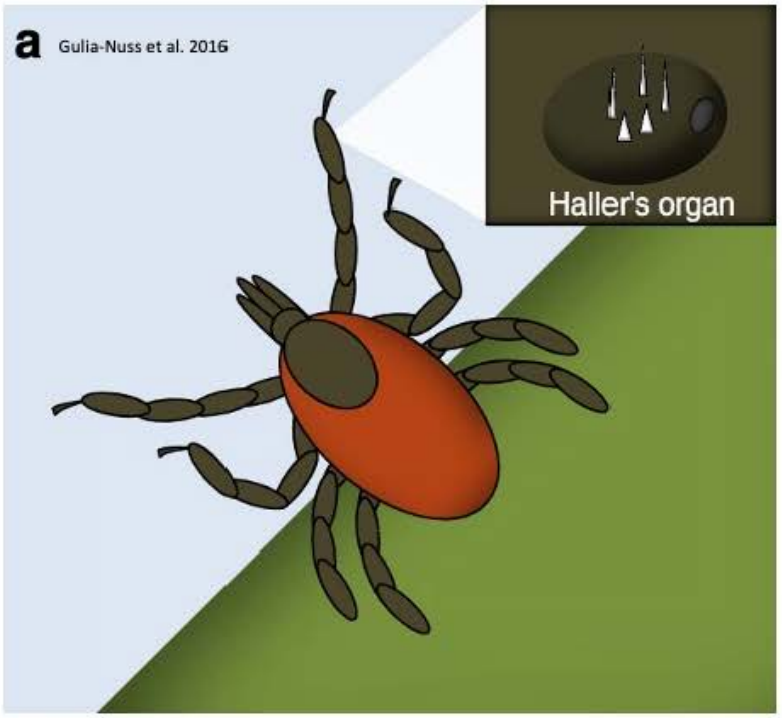
Ticks active 10-12 months of the year



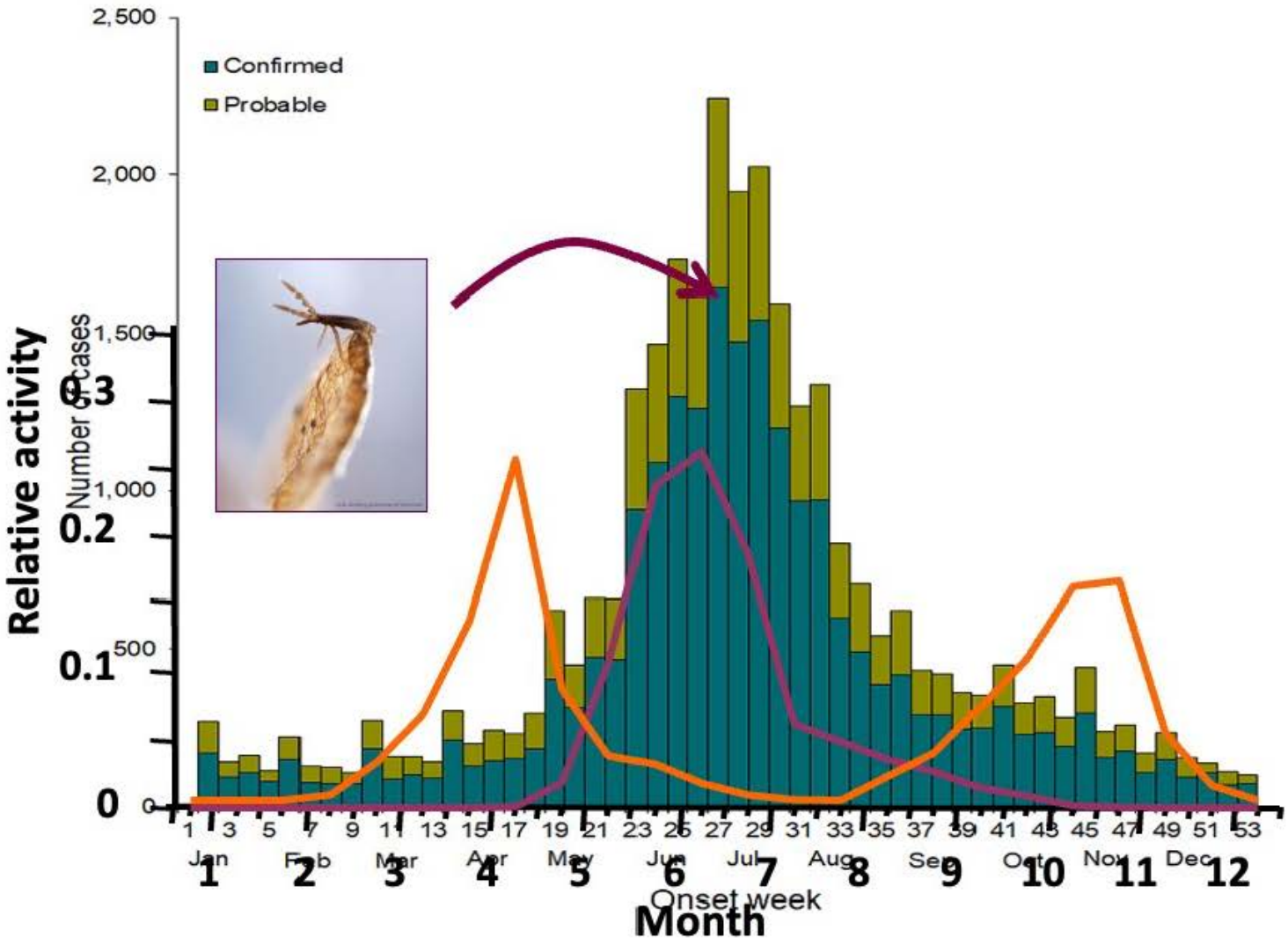
Disease peak coincides with nymphal deer tick abundance

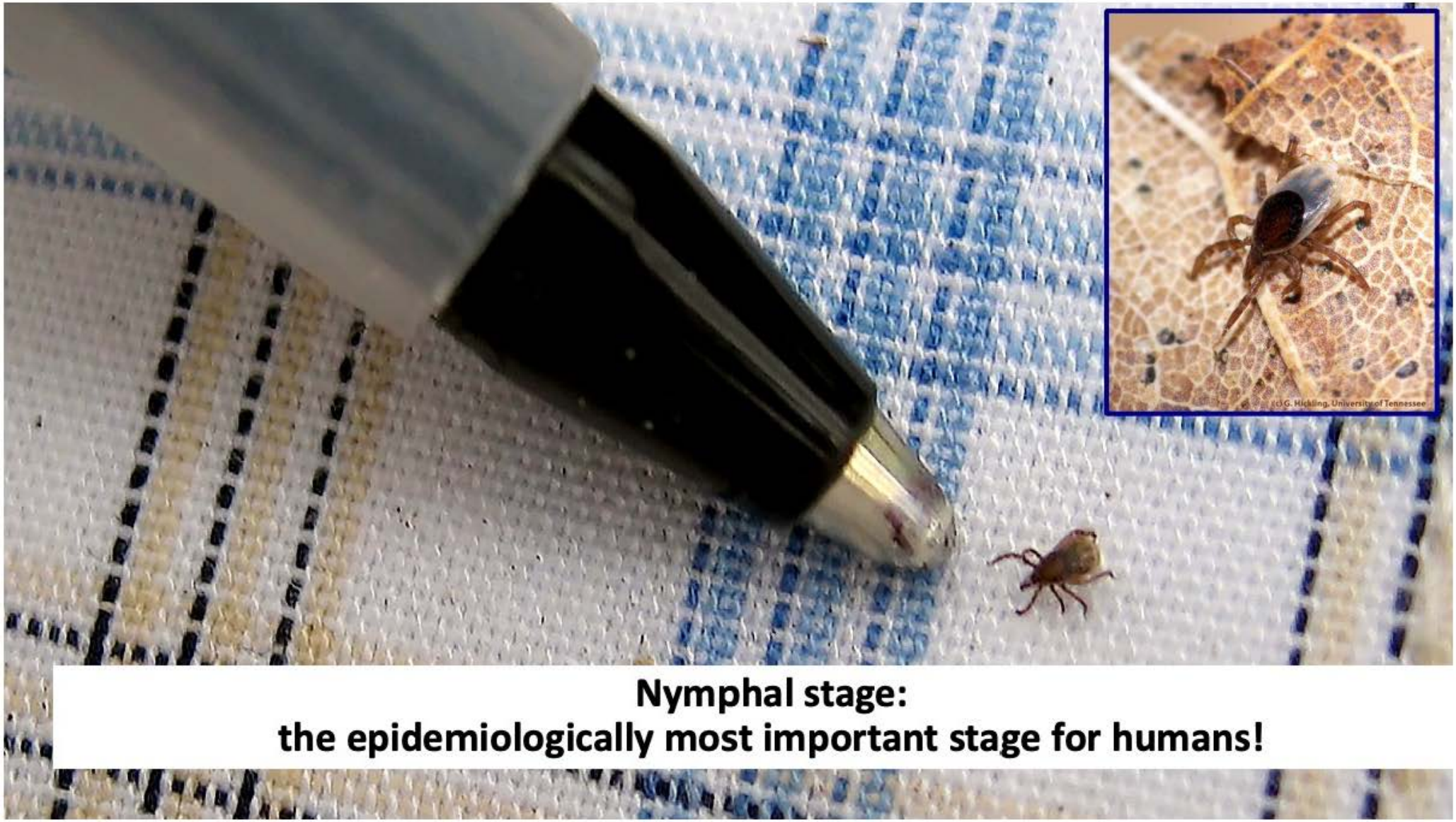
Cdc,.gov

Host seeking behavior



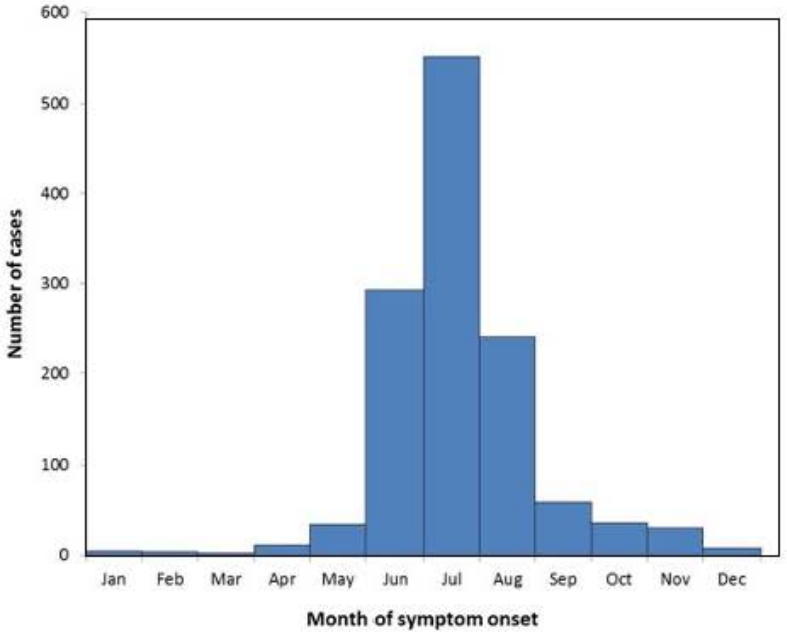
Tick behavior impacts human Lyme disease risk


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

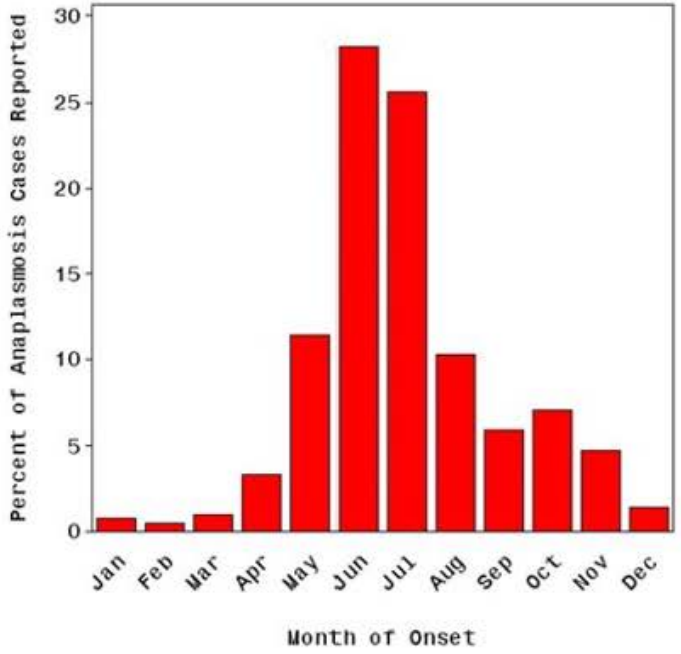


Nymphal stage:
the epidemiologically most important stage for humans!

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

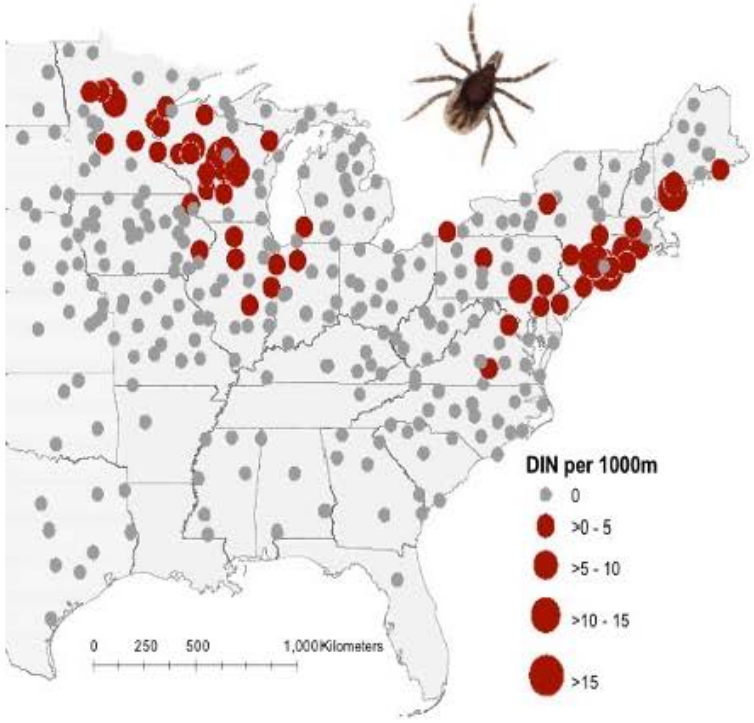


Babesiosis (2013, CDC)



Anaplasmosis (2000-2010, CDC)

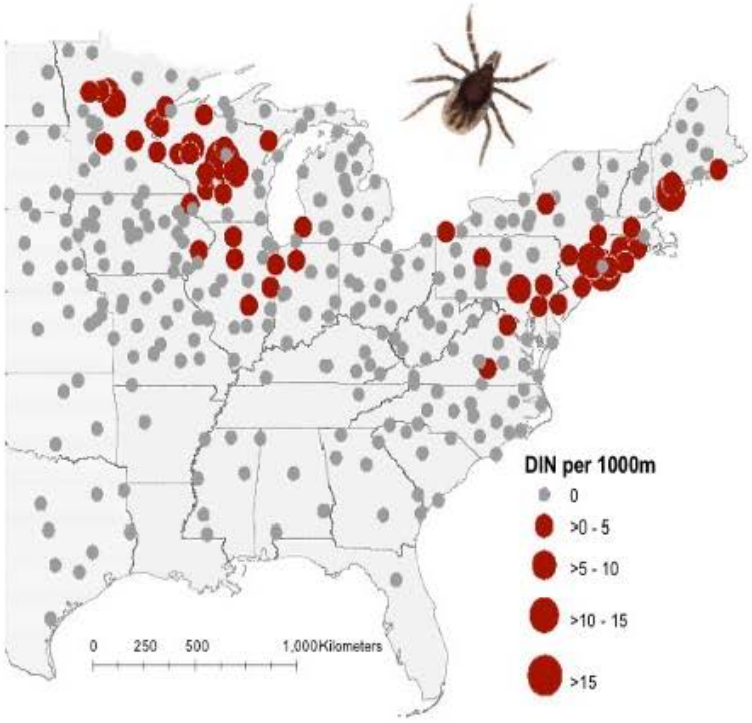
Distribution of questing *I. scapularis* nymphs



Density of infected questing nymphs

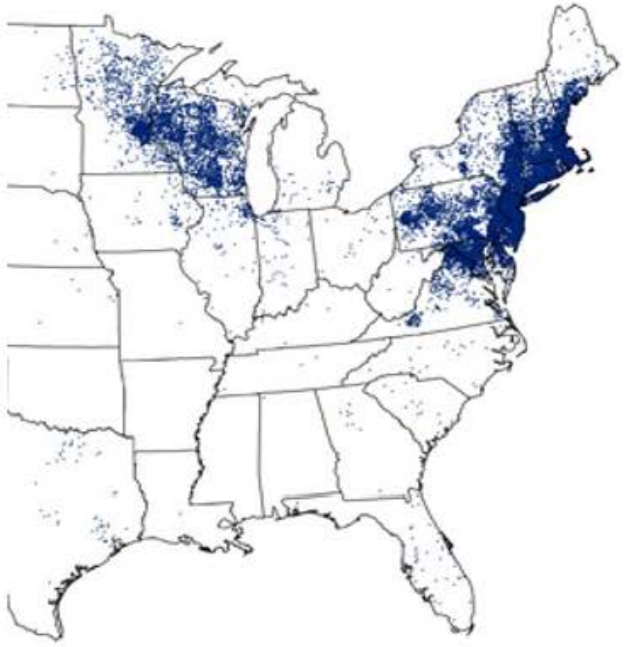
(Diuk-Wasser et al. 2012)

Lyme disease distribution matches QUESTING nymphs distribution



Density of infected questing nymphs

(Diuk-Wasser et al. 2012)

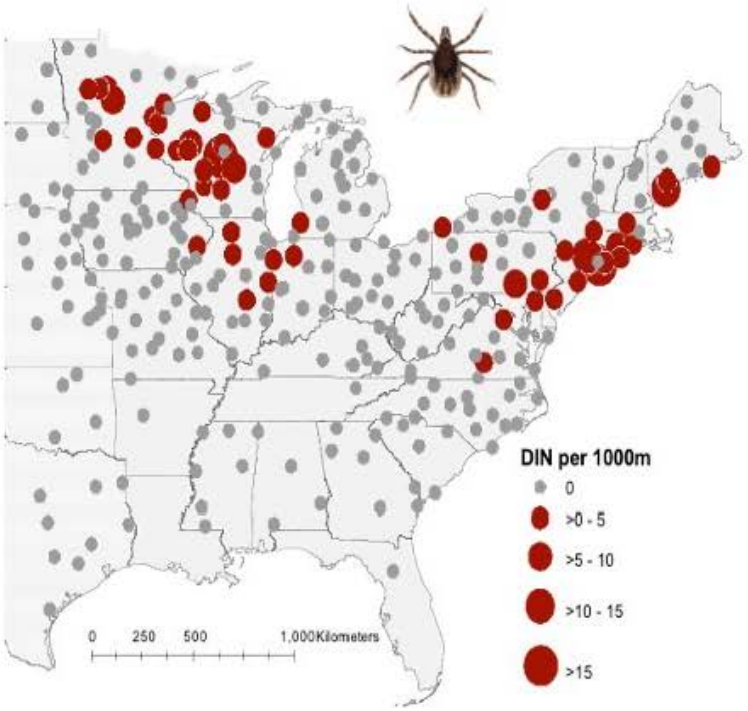


Lyme disease cases

(CDC 2012)

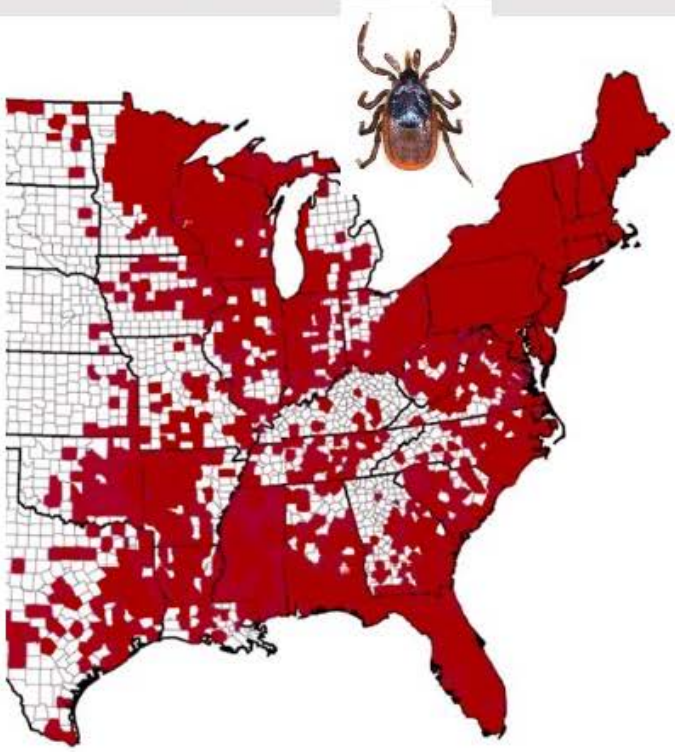
But ...

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



Density of infected questing nymphs

(Diuk-Wasser et al. 2012)



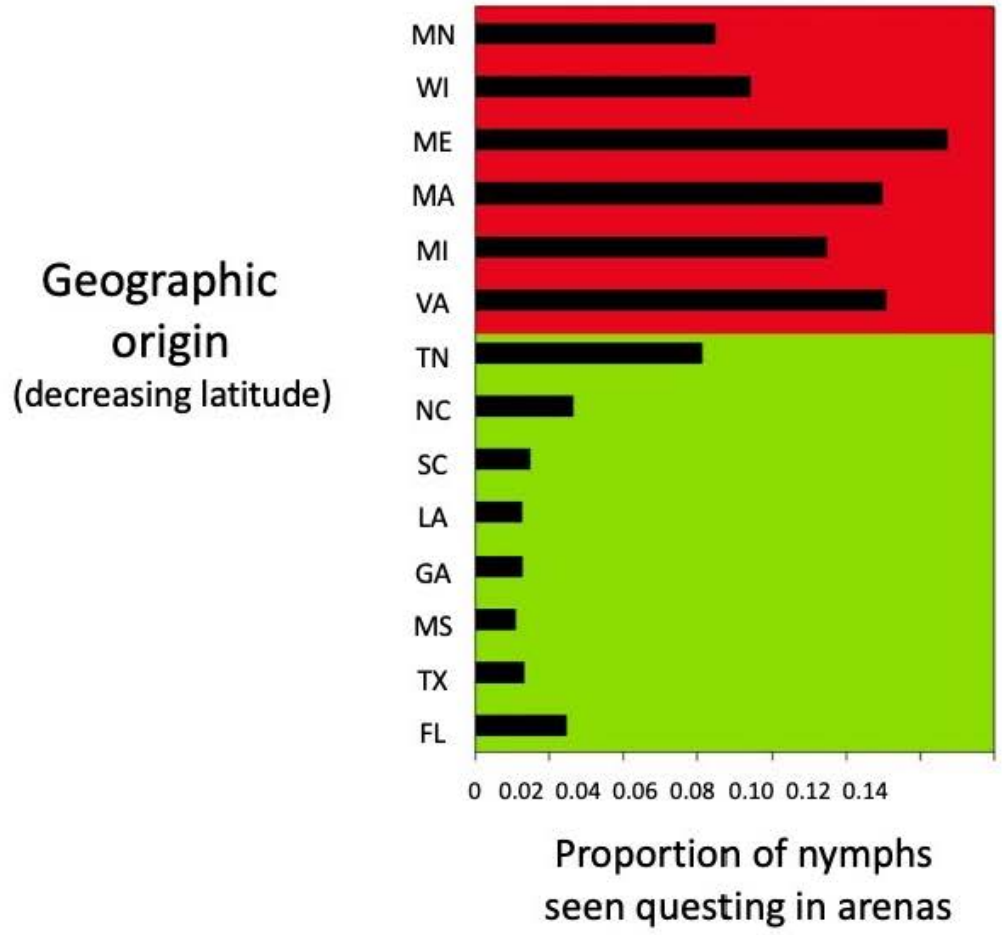
Counties with *I. scapularis* present

(Eisen et al. 2016)

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

Scored questing behavior (2 min)

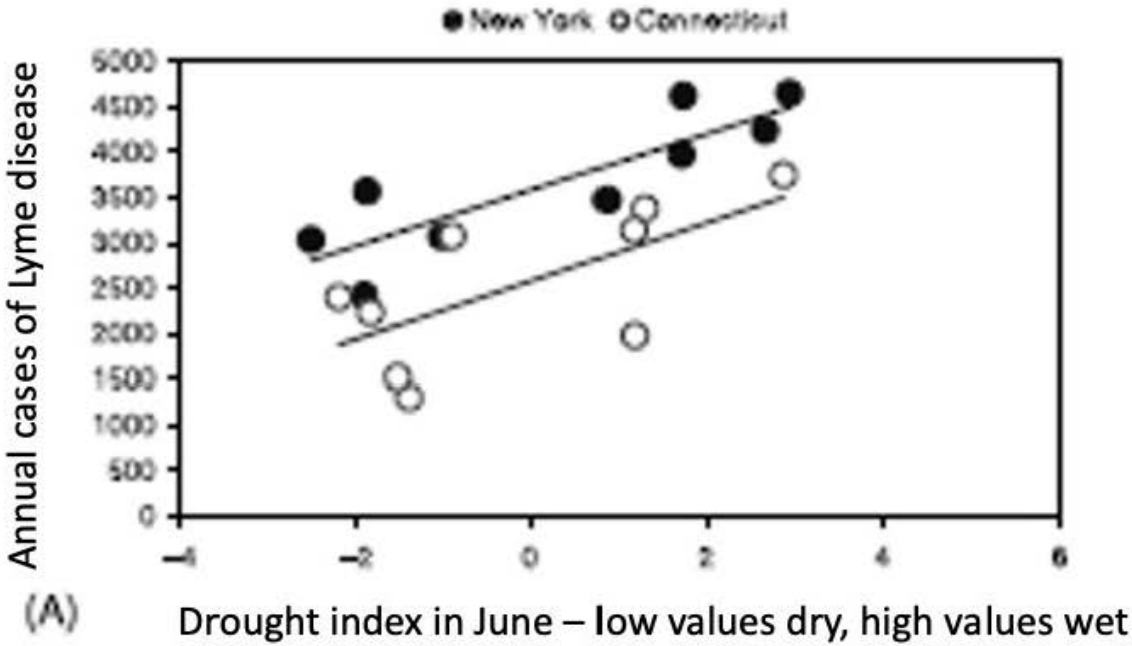
Results: Questing behavior of nymphs correlates with pattern of human LD risk



Arsnoe et al. 2019

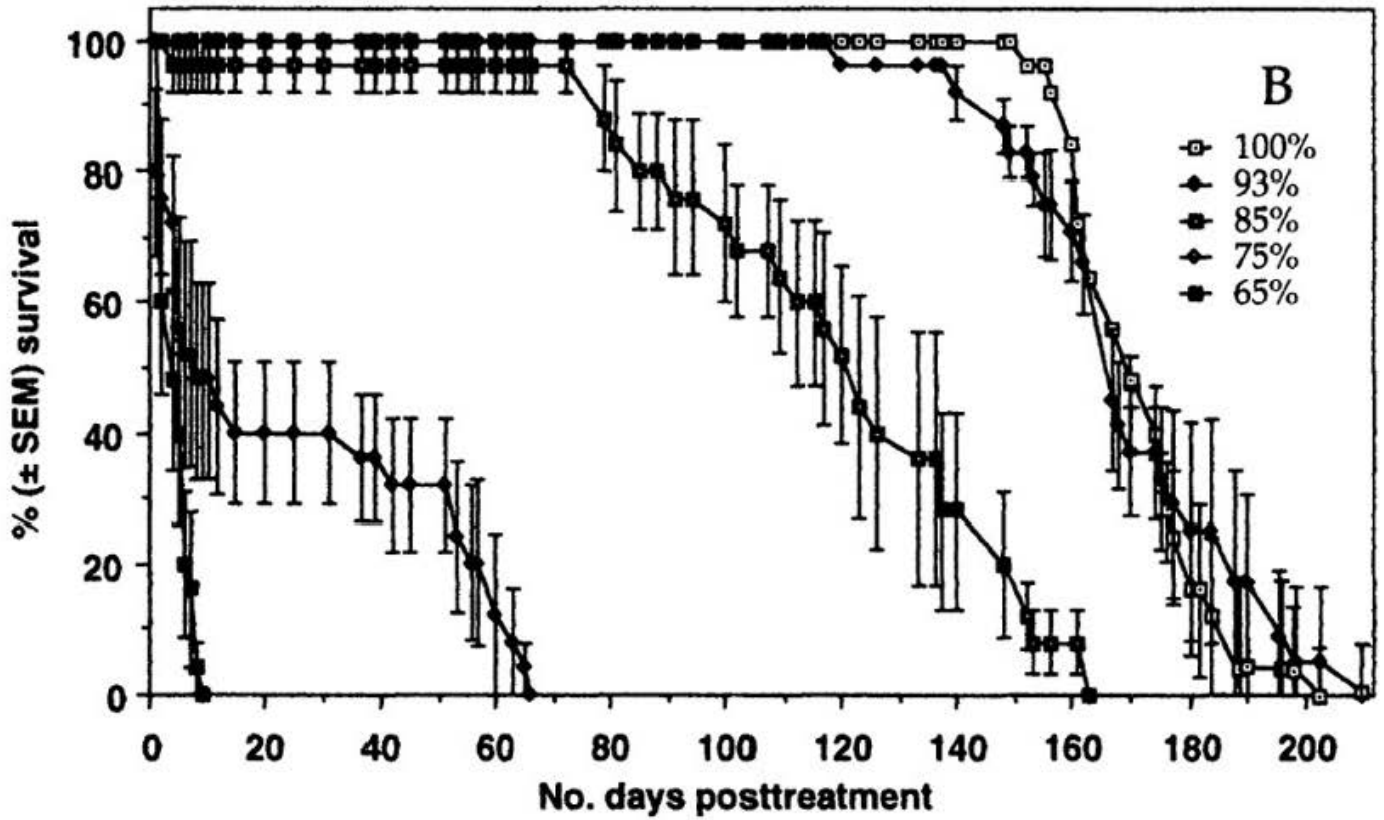
Environmental factors - Moisture

Relationship of Lyme disease to environmental moisture



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

Impact of relative humidity on ticks



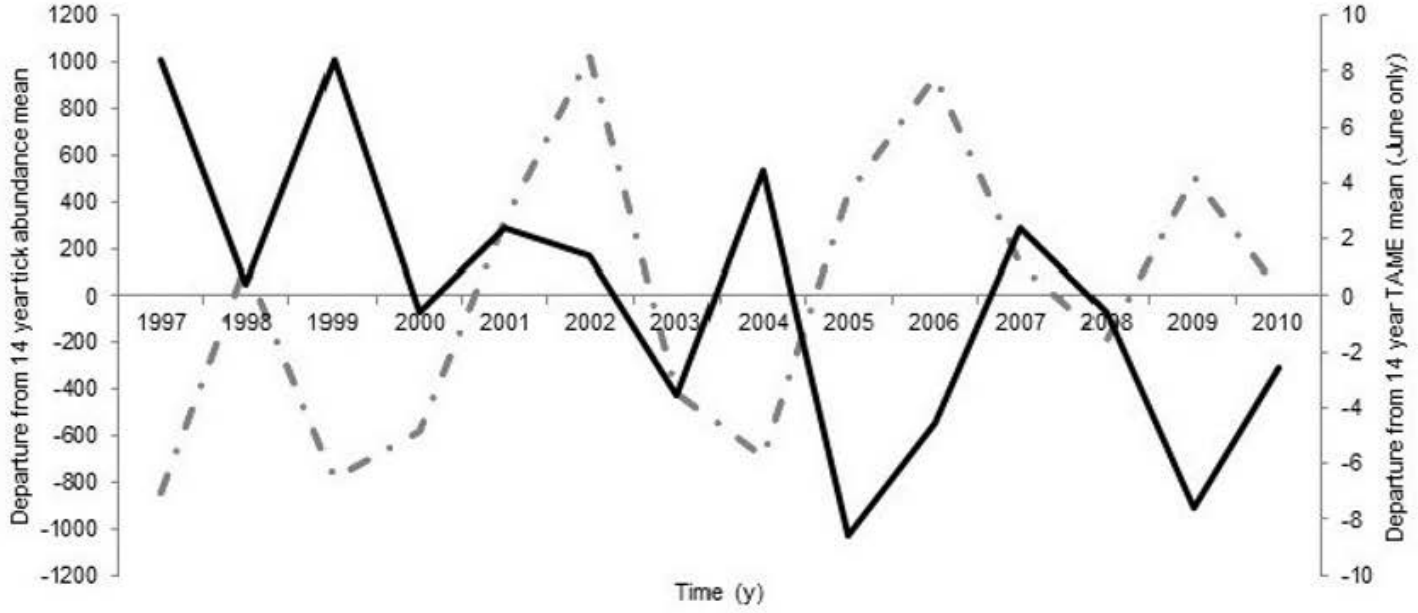
Stafford. 1994. *J. Med. Entomol.* 31:310-314

Research | Open Access | Published: 14 April 2014

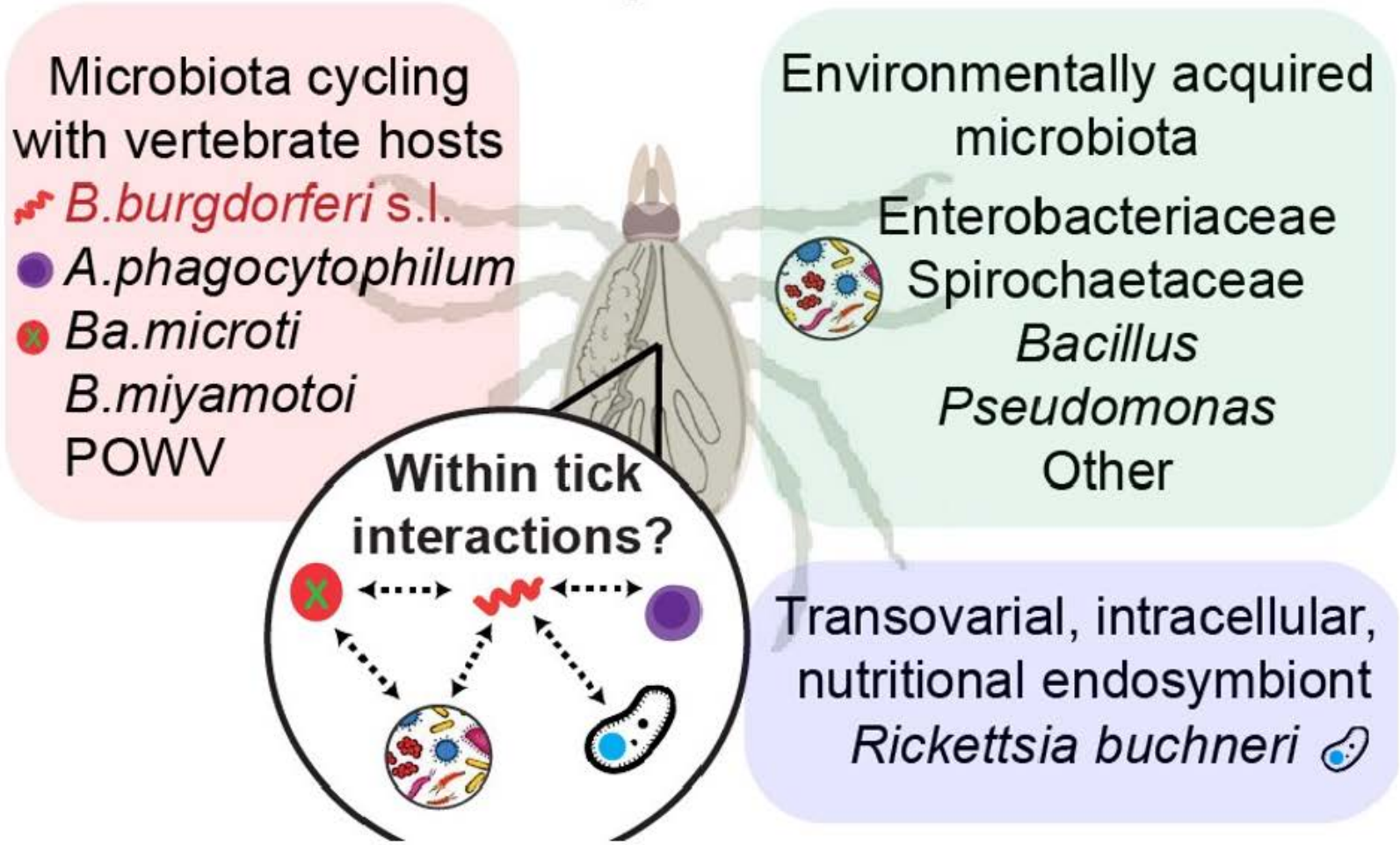
Adverse moisture events predict seasonal abundance of Lyme disease vector ticks (*Ixodes scapularis*)

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

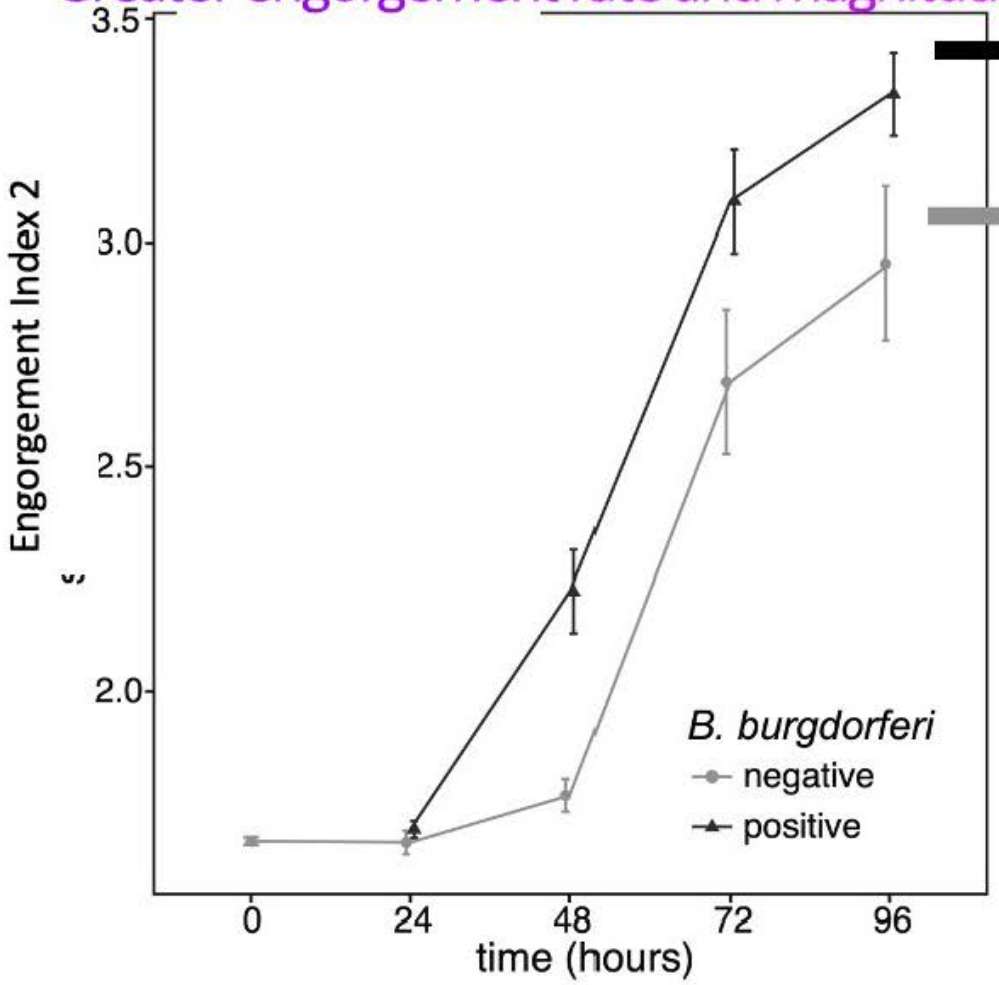


The Tick Microbiome



Microbes are actively interacting with ticks...

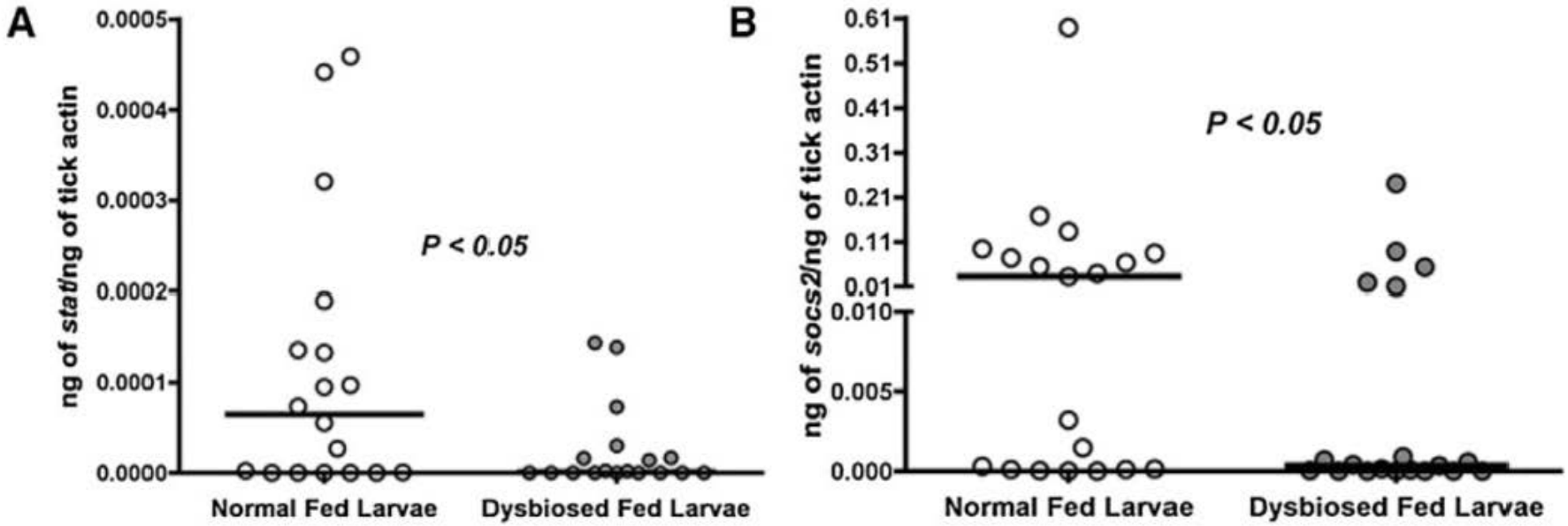
Greater engorgement rate and magnitude in Borrelia burgdorferi infected ticks



Couret et al. 2017

And microbes are actively interacting within ticks…

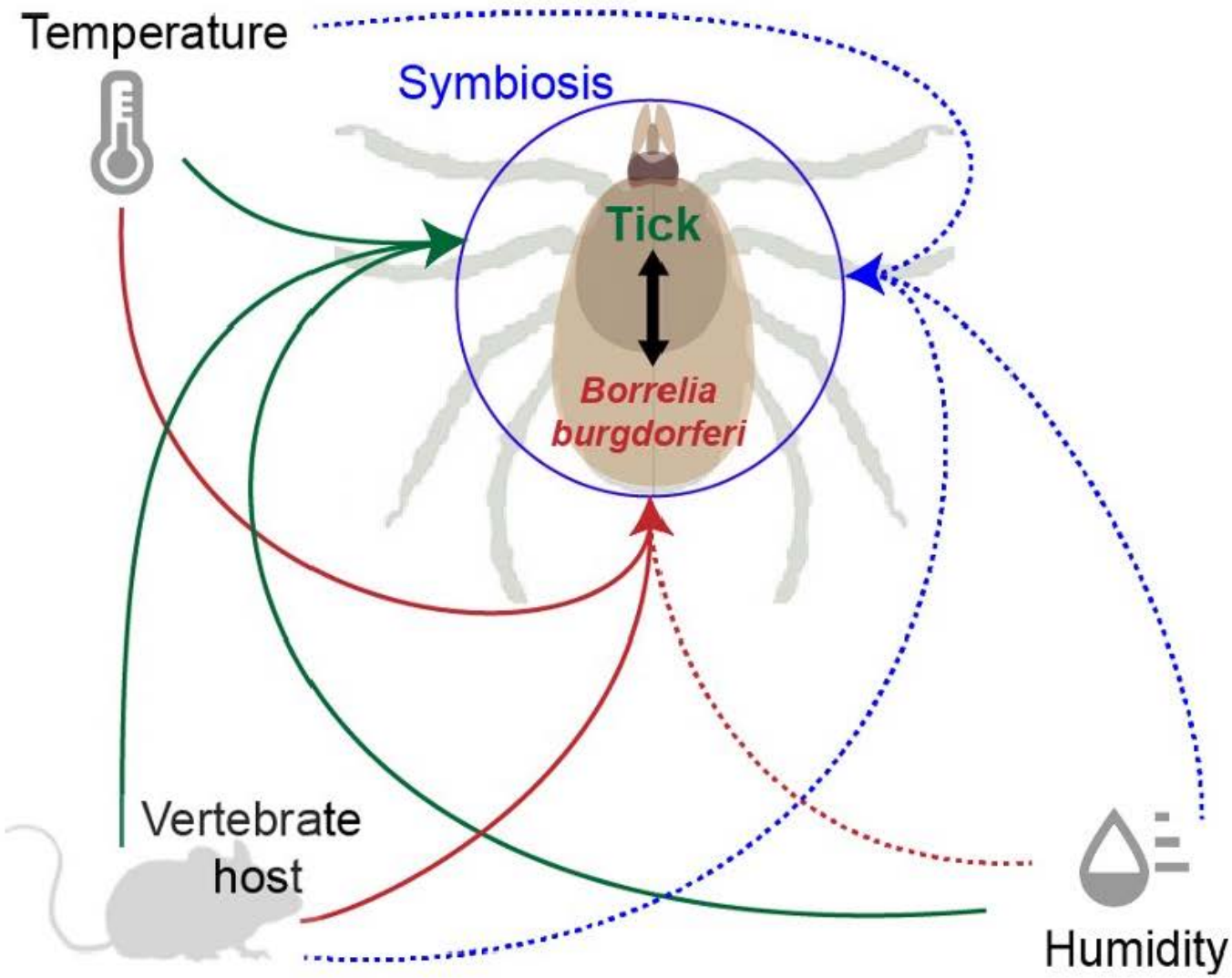
Gut Microbiota of the Tick Vector *Ixodes scapularis* Modulate Colonization of the Lyme Disease Spirochete



Narasimhan et al. 2014

It is an ensemble

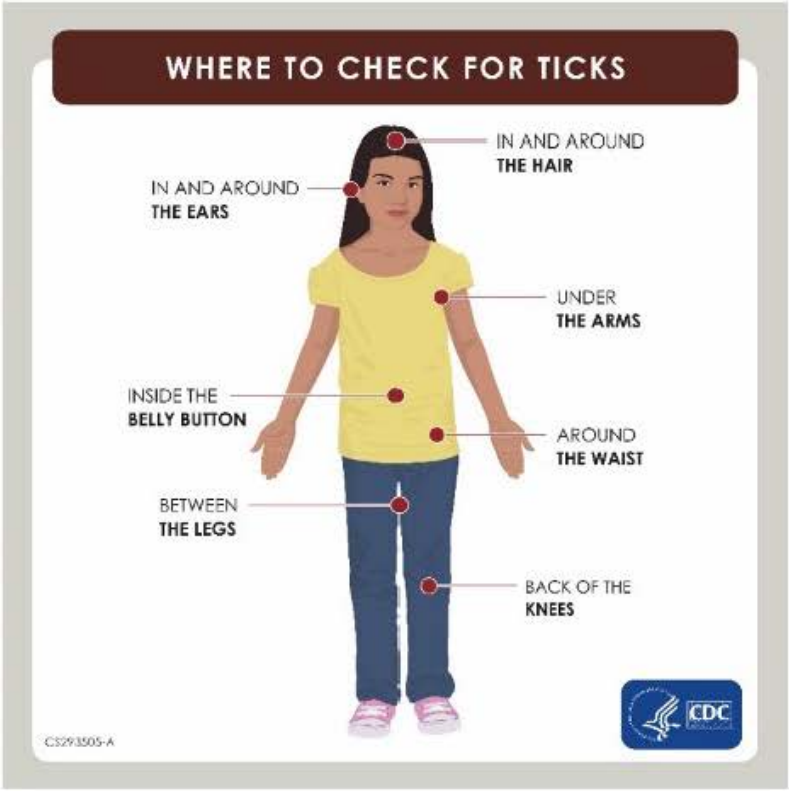
The environment
The tick
The pathogen
The microbiome



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

- 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

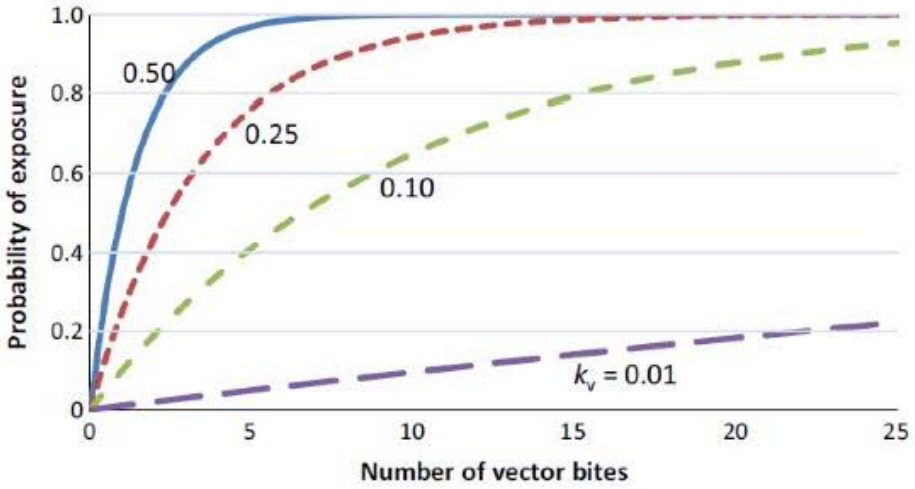
Henderson & Tilton (1955)

% 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 x (1 – (T_a x C_b)/(T_b x C_a))

% Protection

Ginsberg & Couret (2019)

% Protection =

100 x (1 – (P_{eTa} x P_{eCb})/(P_{eTb} x P_{eCa}))

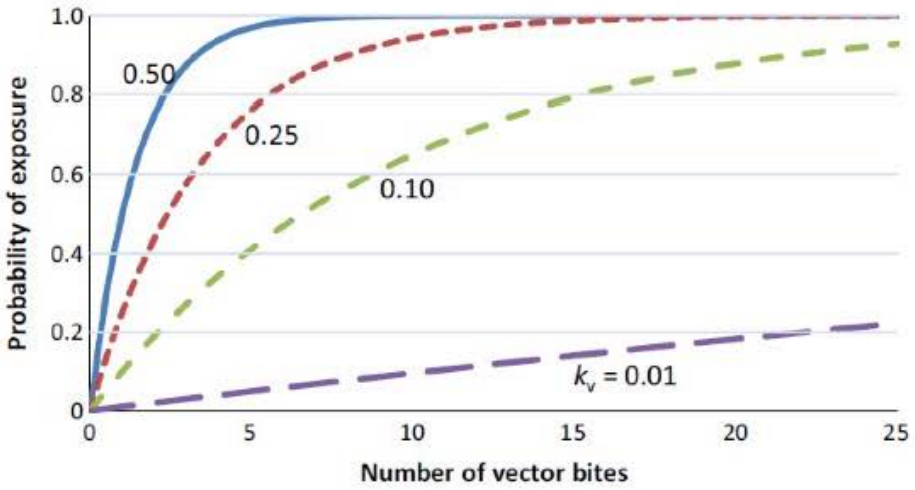
Probability of Exposure P_e

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

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



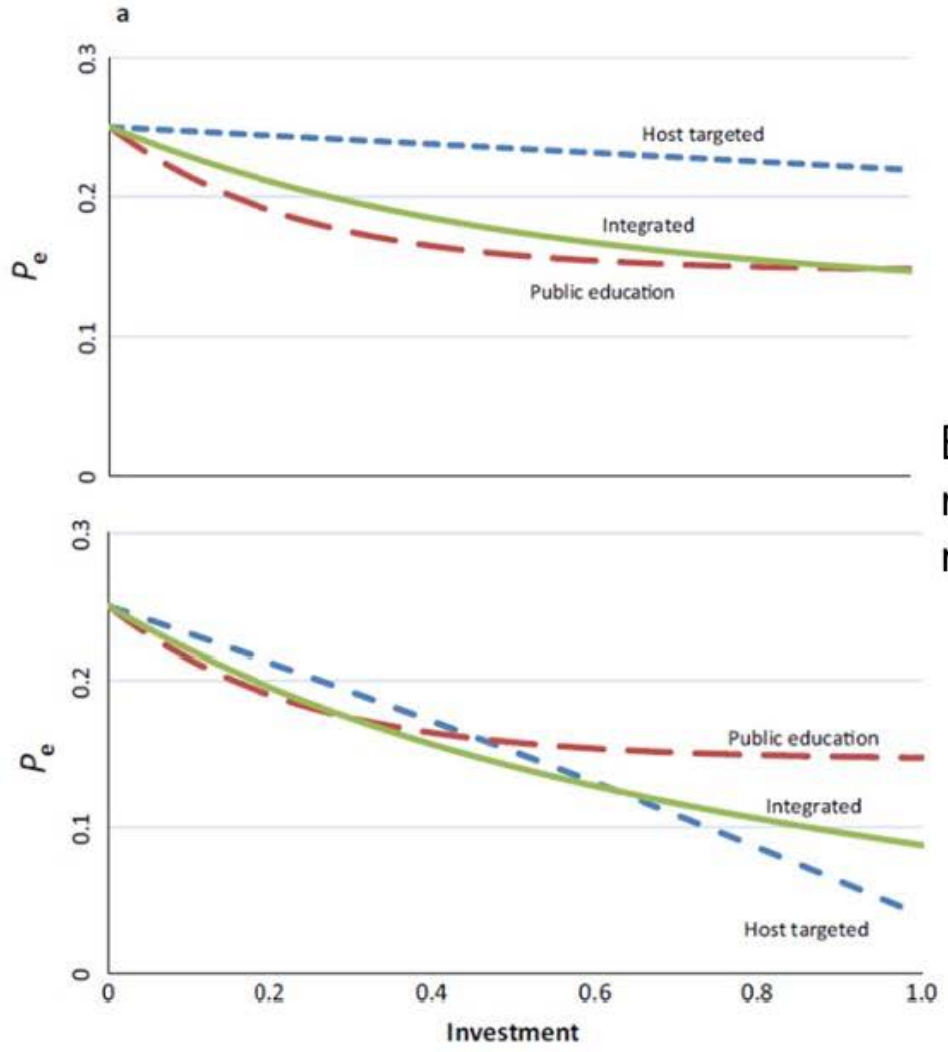
Efficient and Adaptive Management of Lyme Disease

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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