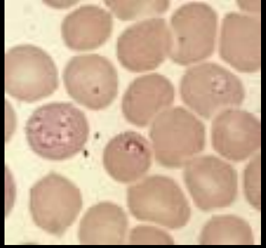
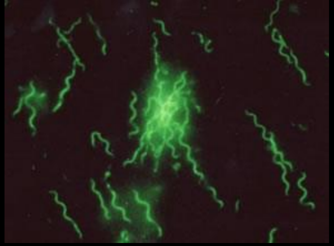




Factors influencing tick-borne pathogen emergence and diversity

Maria Diuk-Wasser
Columbia University

July 13, 2015
NCAR/CDC Climate and vector-borne disease workshop

Take home

1. Tick-borne diseases are expanding for reasons beyond climate

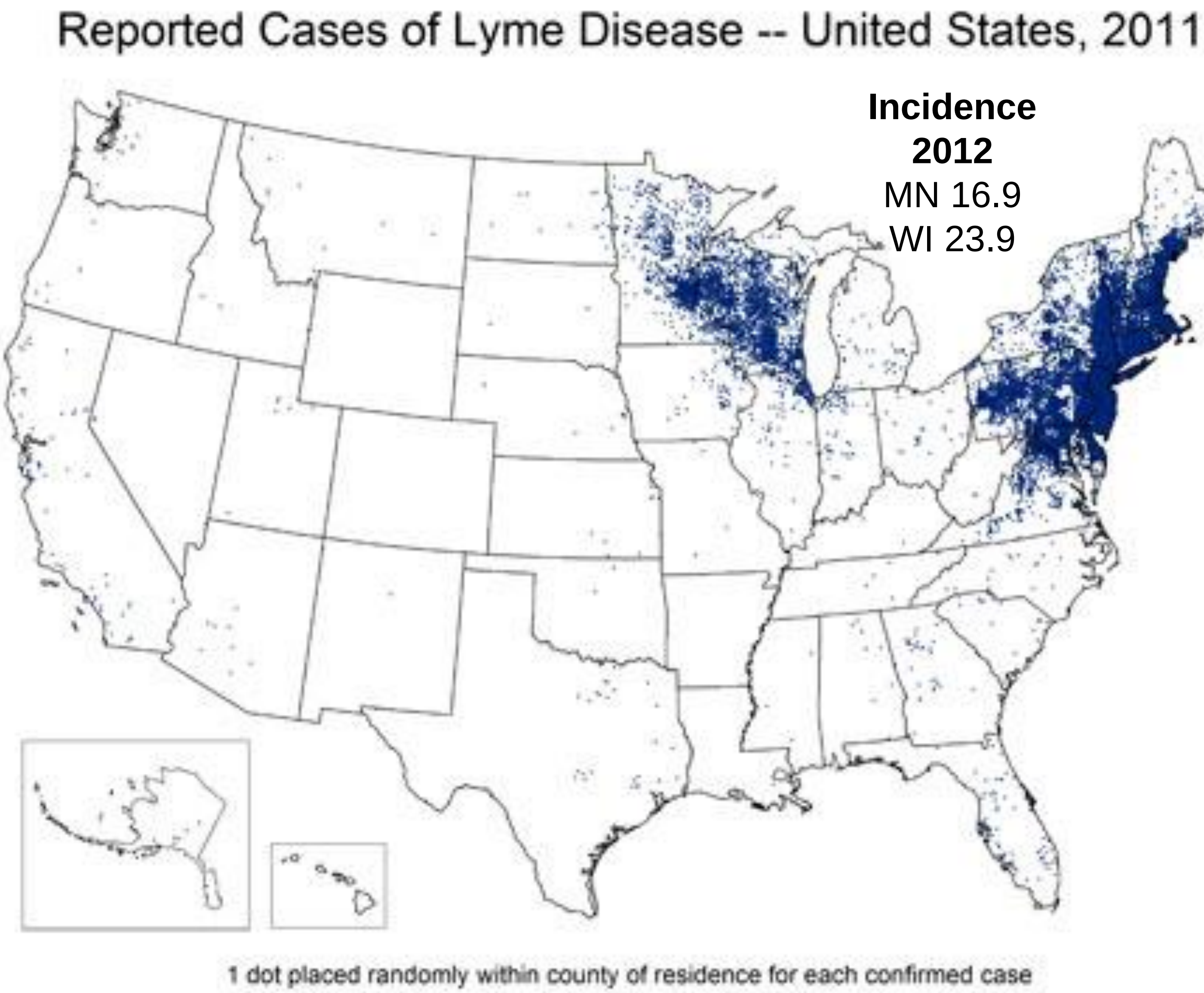
2. Ticks are not mosquitoes

3. Climatic limits and effects of seasonality on tick and pathogen life cycles

4. Beyond Lyme: co-emergence of multiple pathogens

Tick-borne diseases are expanding for reasons beyond climate

Lyme disease is expanding



Incidence 2012
MN 16.9
WI 23.9

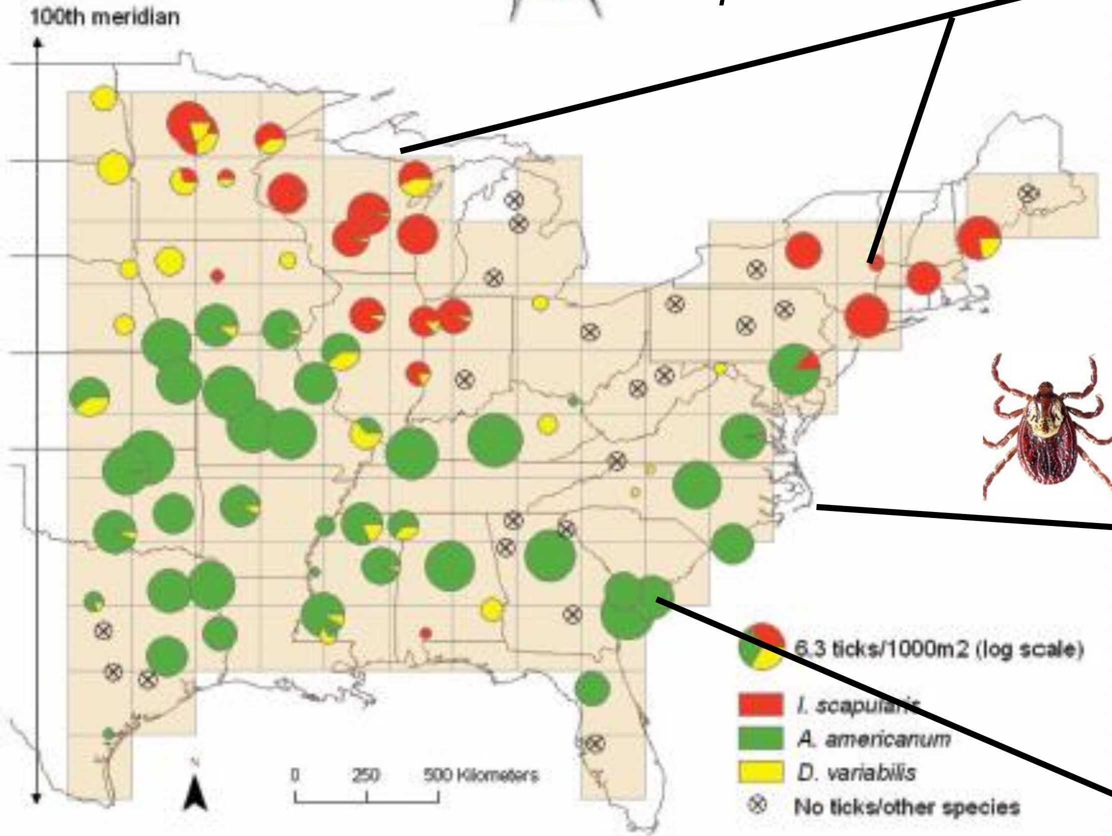
Incidence 2012
CT 46.0
MA 51.1
ME 66.6
NJ 30.8
NY 10.4
PA 32.5

CDC

Emerging tick-borne pathogens in the US

Ixodes scapularis

- *Borrelia burgdorferi*
- *Babesia microti*
- *Anaplasma phagocytophilum*
- Deer tick virus
- *Borrelia miyamotoi*
- *Ehrlichia muris*- like (EML)



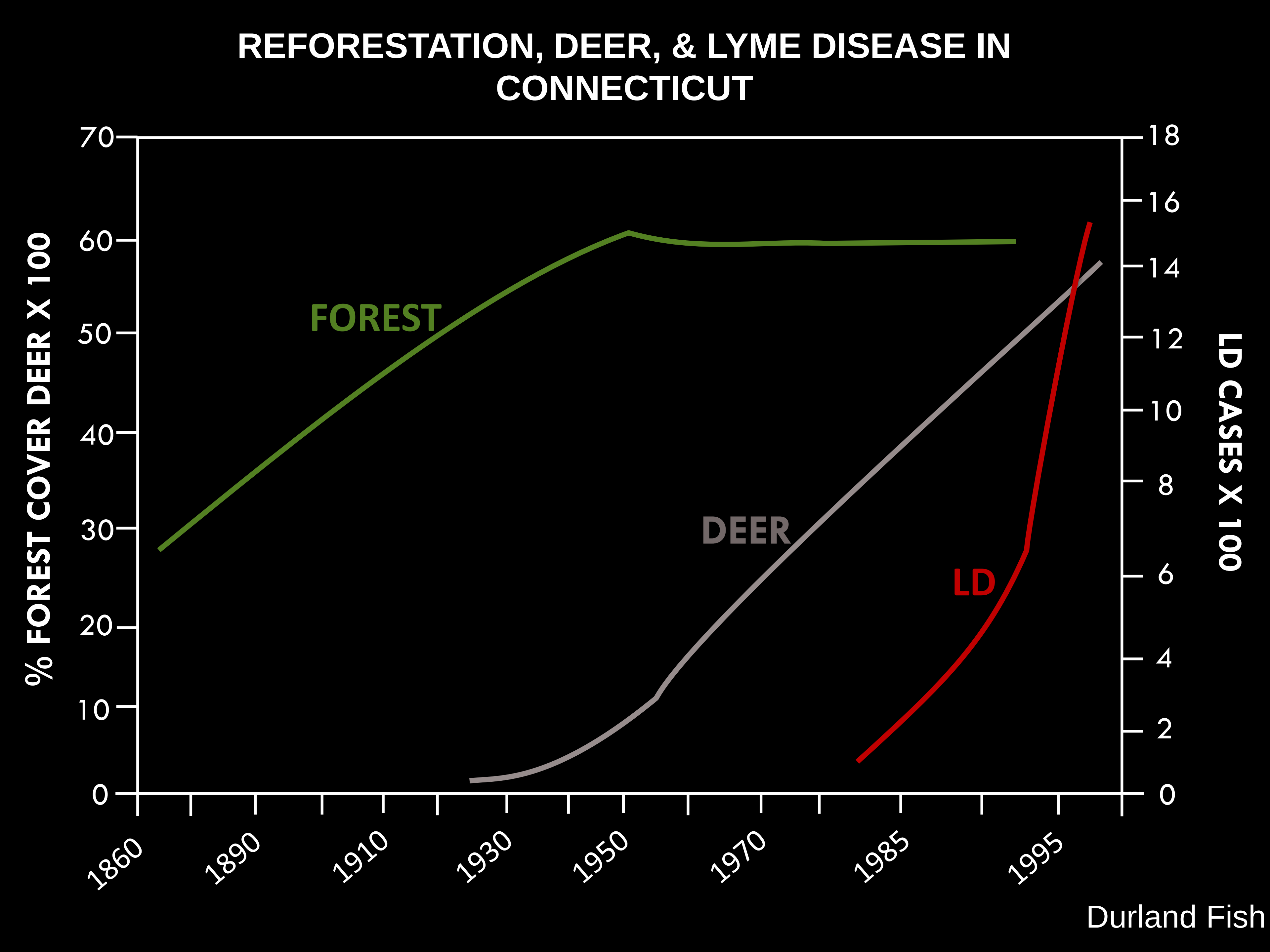
Dermacentor variabilis

- *Rickettsia rickettsii*
- *Francisella tularensis*

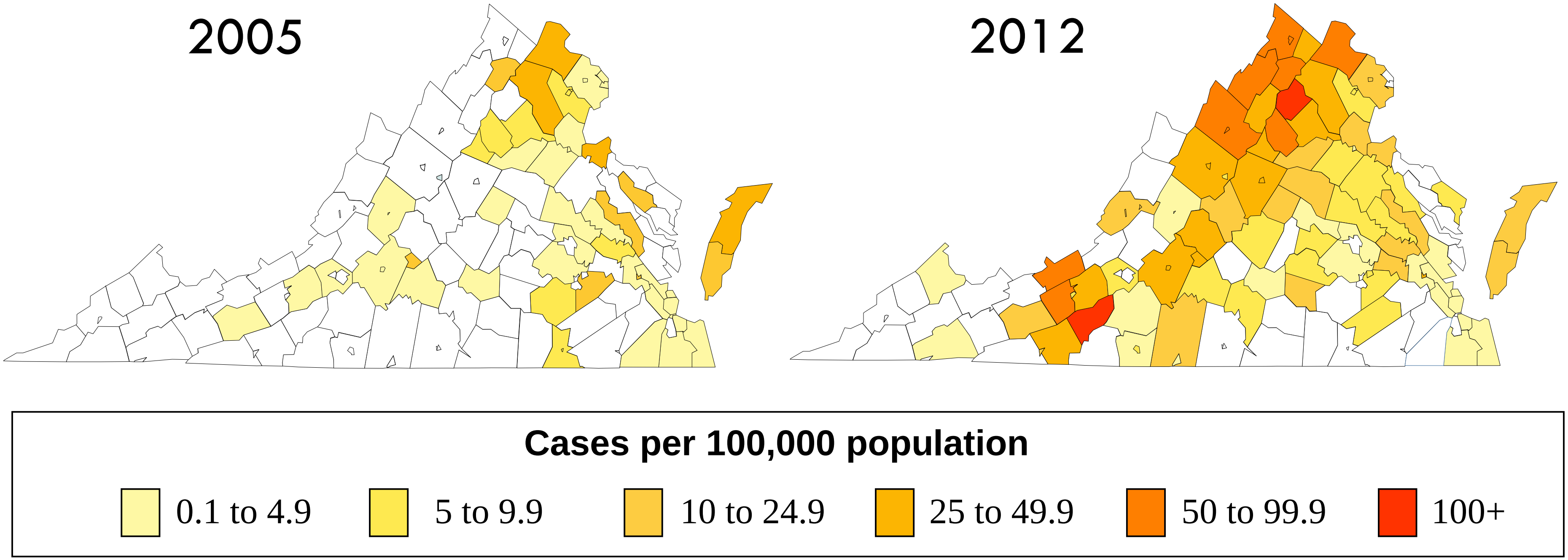
Amblyomma americanum

- *Ehrlichia chaffeensis*
- *Ehrlichia ewingii*
- *Francisella tularensis*

Diuk-Wasser, JME, 2006

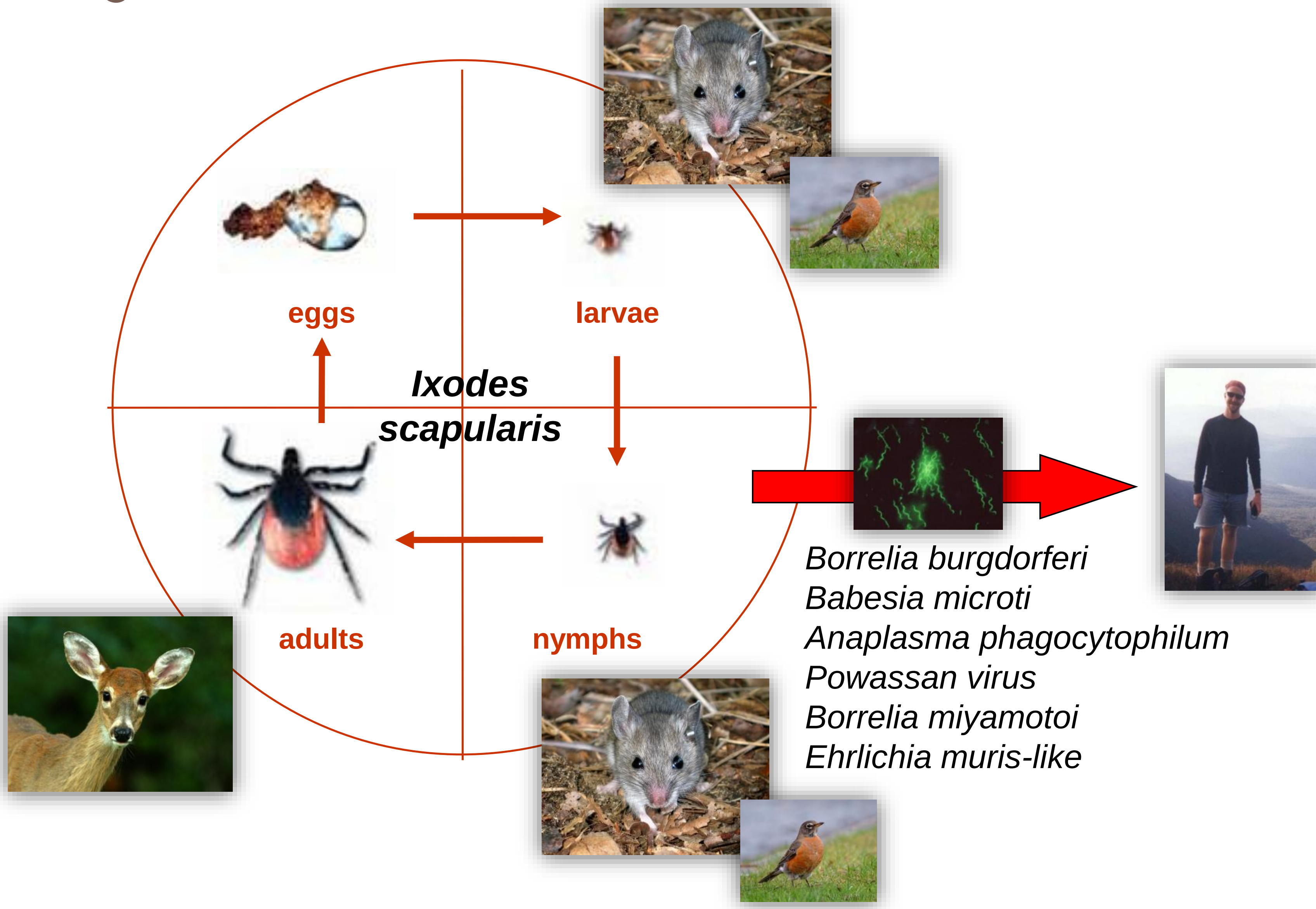

REFORESTATION, DEER, & LYME DISEASE IN CONNECTICUT
% FOREST COVER DEER X 100
LD CASES X 100
FOREST
DEER
LD
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
1860
1890
1910
1930
1950
1970
1985
1995
Durland Fish

Lyme disease is also increasing in the South: Incidence in Virginia, 2005 & 2012

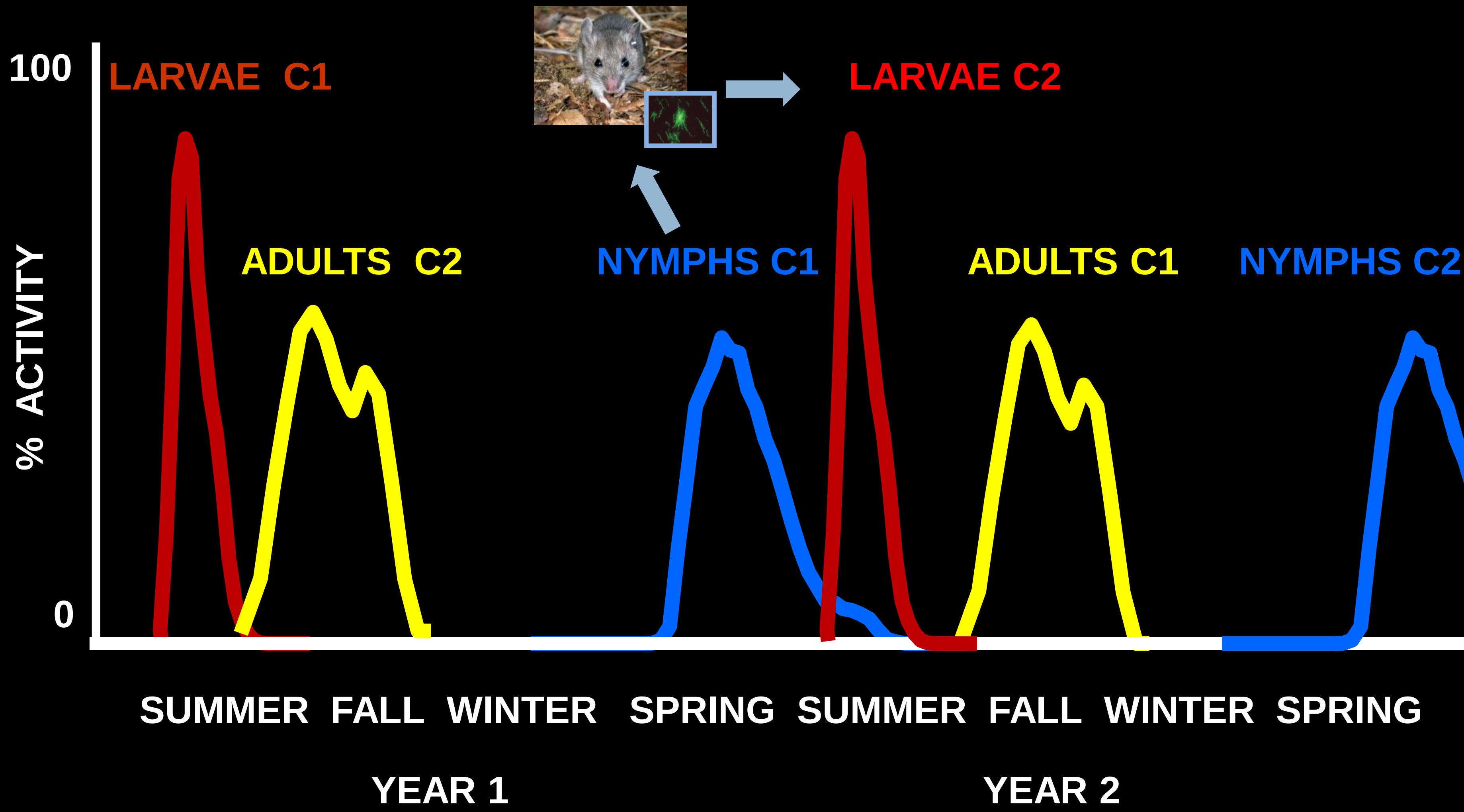


Ticks are not mosquitoes

Ixodes scapularis life cycle and tick-borne pathogen transmission



Tick life cycle



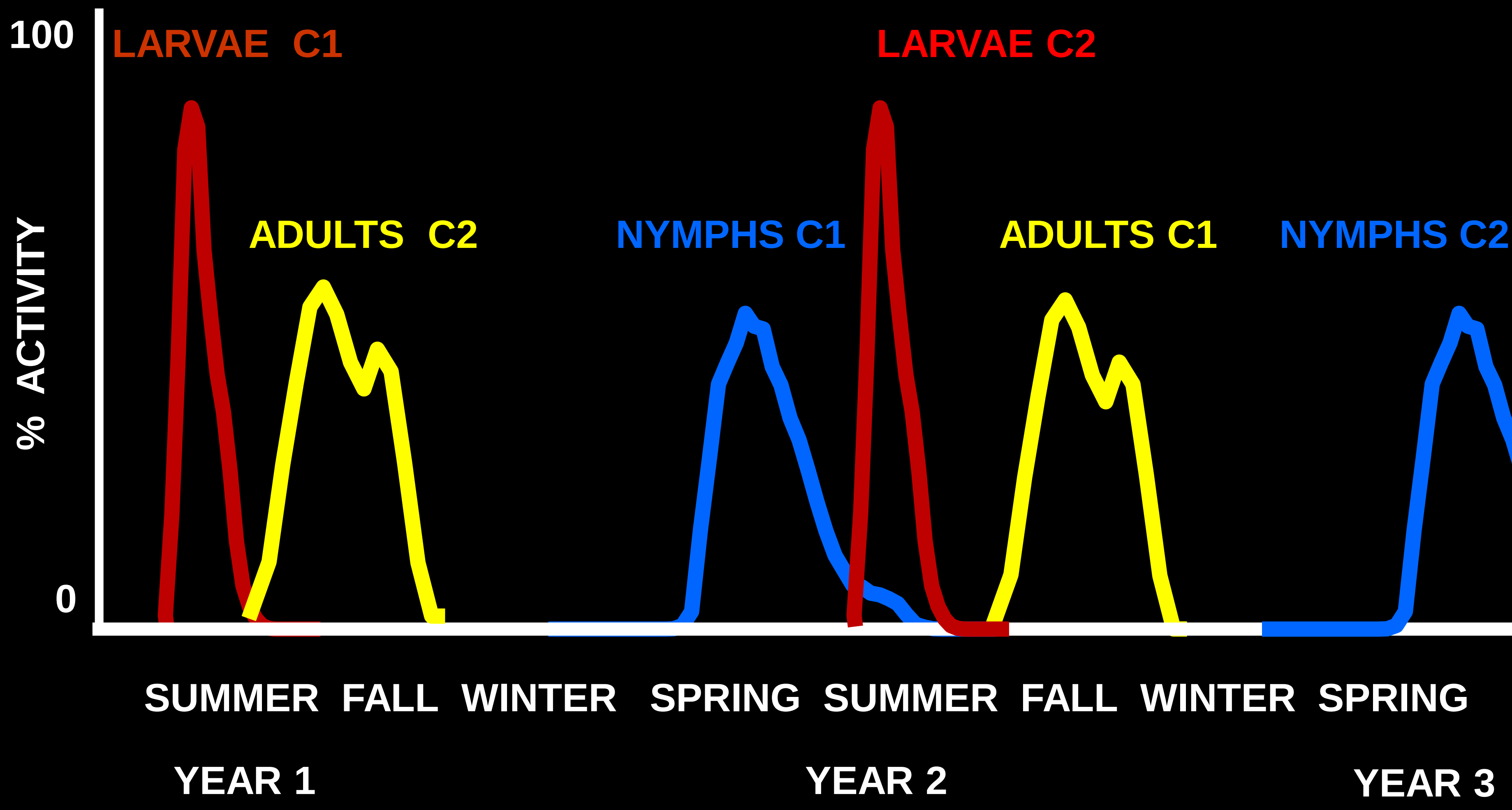
Climate limits and seasonality

Effects on tick life cycle

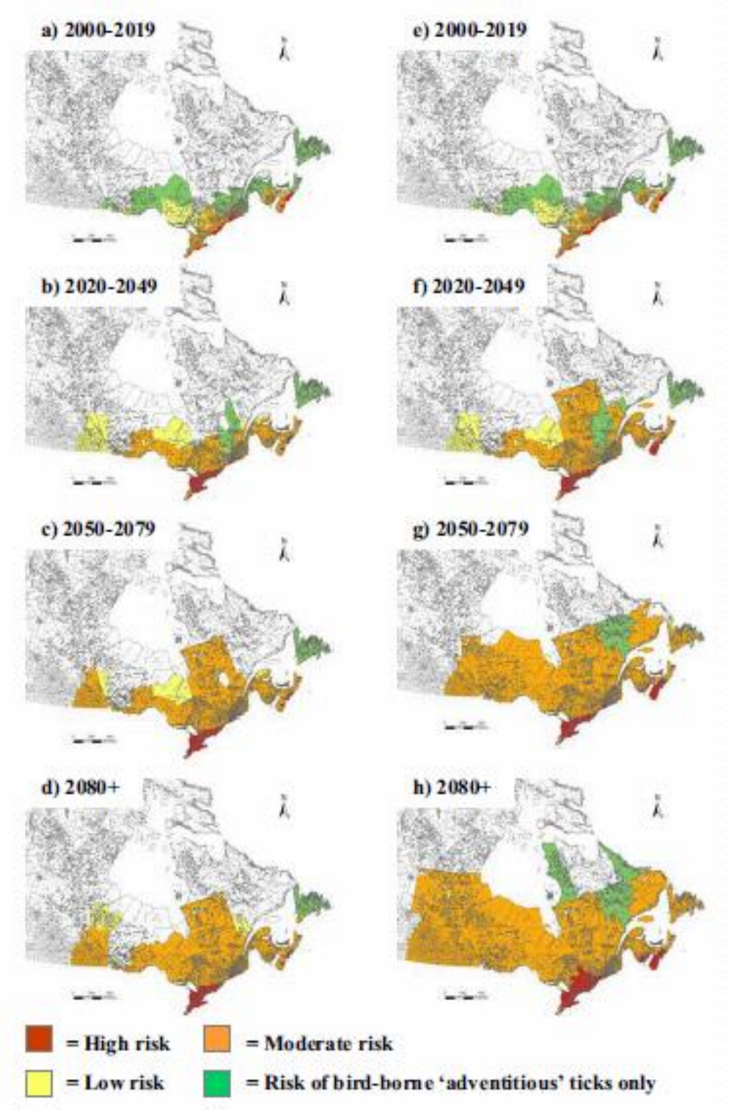
Environmental factors limiting tick distribution

- High vapor pressure deficit reduces tick survival
- High vapor pressure reduces host seeking activity and thus the likelihood of finding a host
  - To seek or not to seek: to die of hunger or of thirst
- Low temperature can kill overwintering ticks
- Low temperature can slow down tick development

Larvae overwinter as larvae when they can't develop fast enough or it gets cold too fast

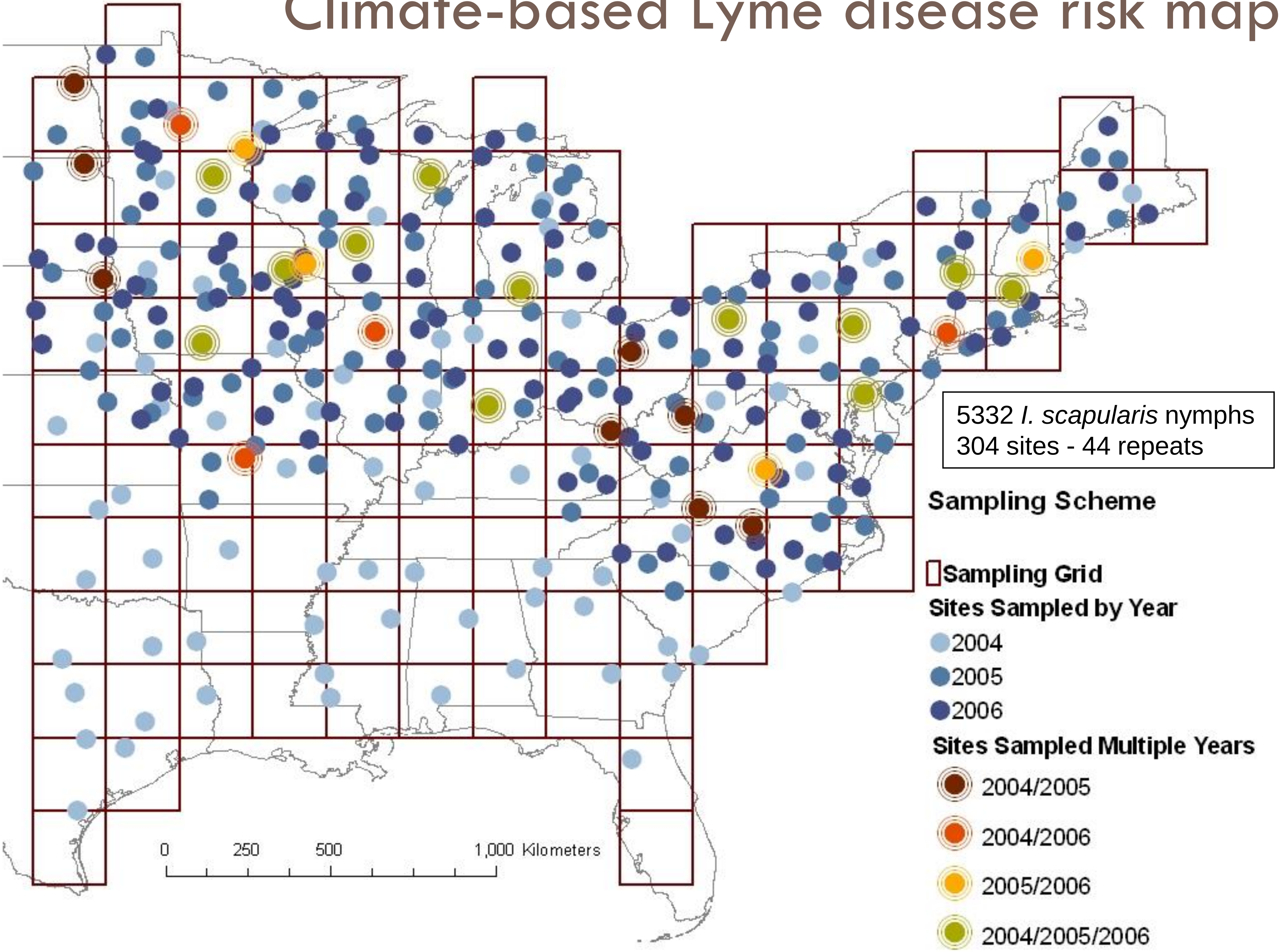


Risk map *Ixodes scapularis* range expansion into Canada with climate change



Ogden et al. 2008

Climate-based Lyme disease risk map



Environmental predictors for the density of nymphs

- Forest density and fragmentation
- Soil texture

Climate

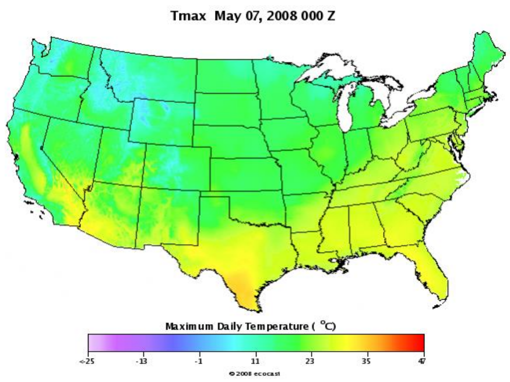
- Maximum temperature
- Minimum temperature
- Vapor pressure deficit
- Precipitation

Summarized by:
Monthly mean over 20 years
Fourier transformed variables over 57 years

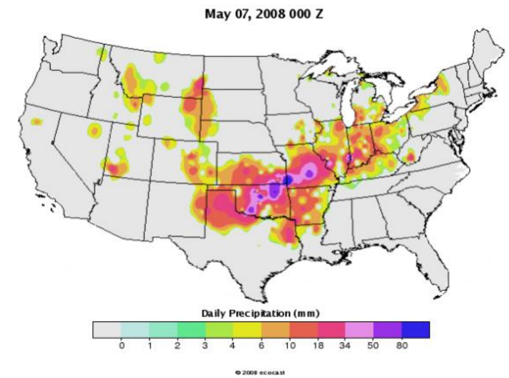
U.S. meteorological surfaces
Terrestrial Observation and Prediction System

http://ecocast.arc.nasa.gov/

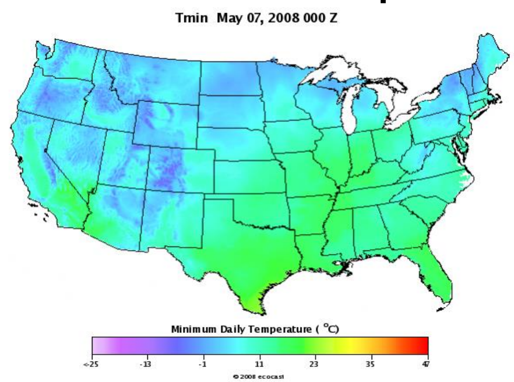
Maximum Temp



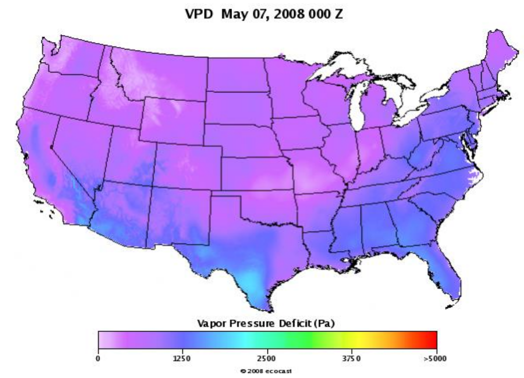
Precipitation



Minimum Temp



Vapor Pressure Deficit

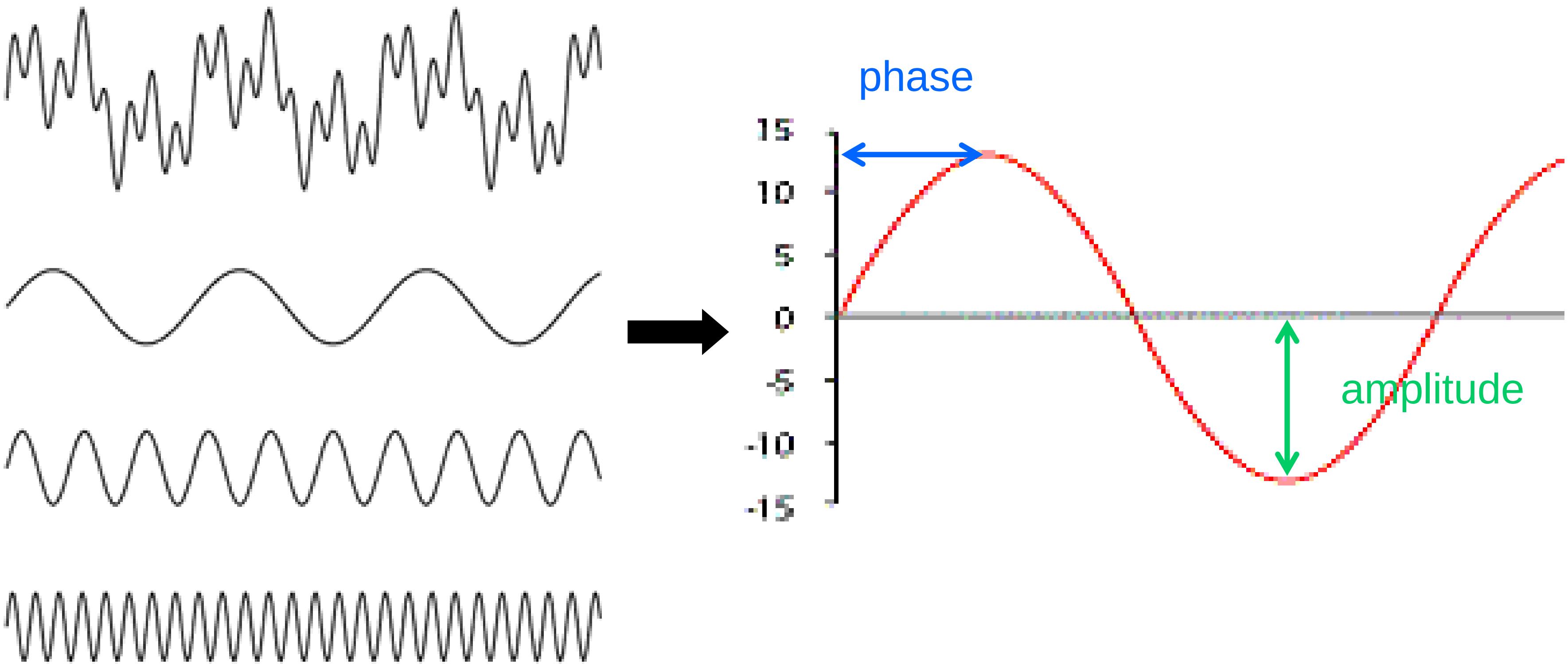


U.S. meteorological surfaces interpolated daily at 8 km spatial resolution from observations at more than 3,000 meteorological stations.

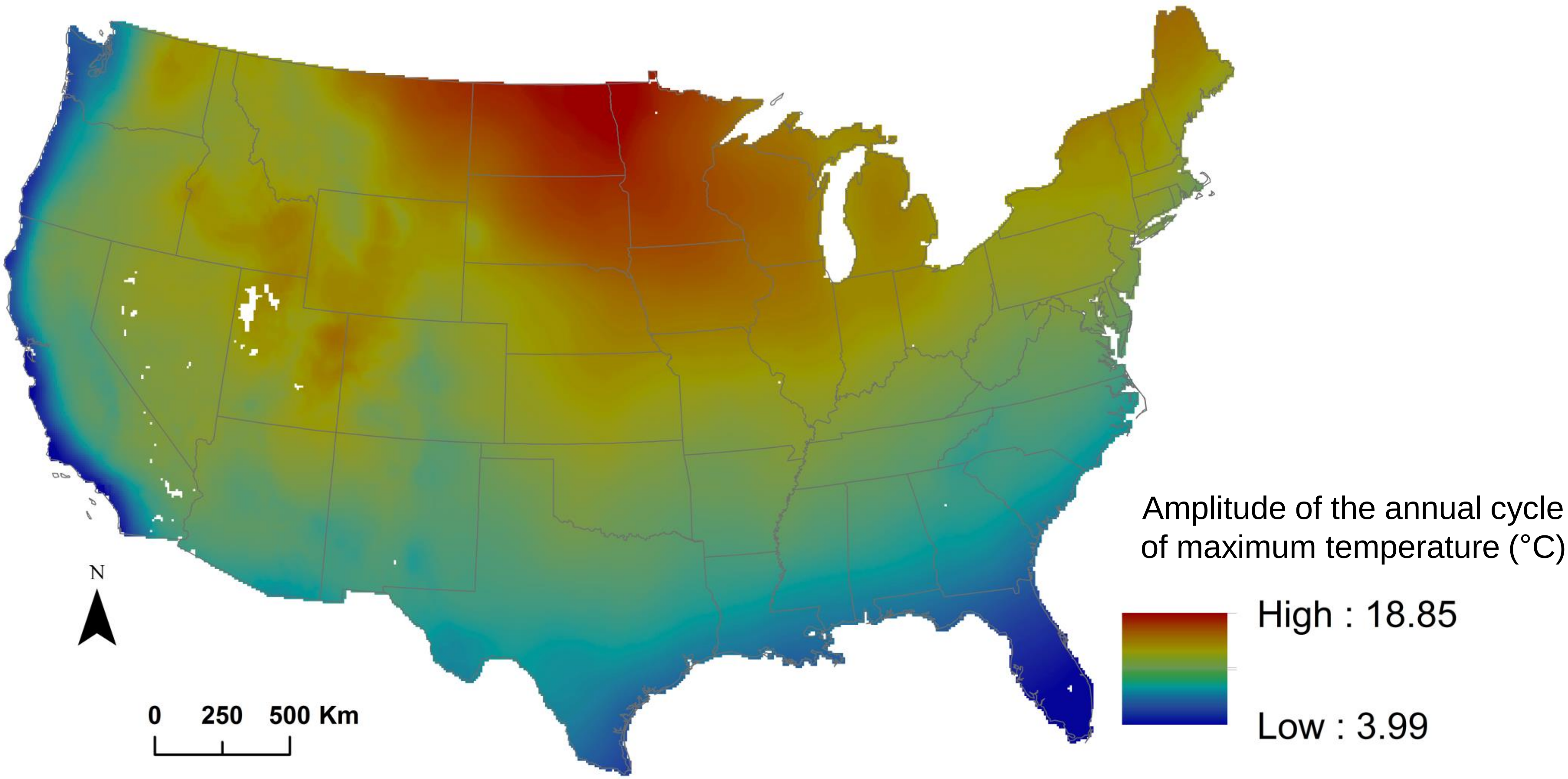
Nemani et al., 2003 and 2007
Jolly et al., 2005;
Thornton et al., 1999

Temporal Fourier analyses

Set of orthogonal variables that capture the seasonality



Amplitude of the annual cycle of maximum temperature (°C)

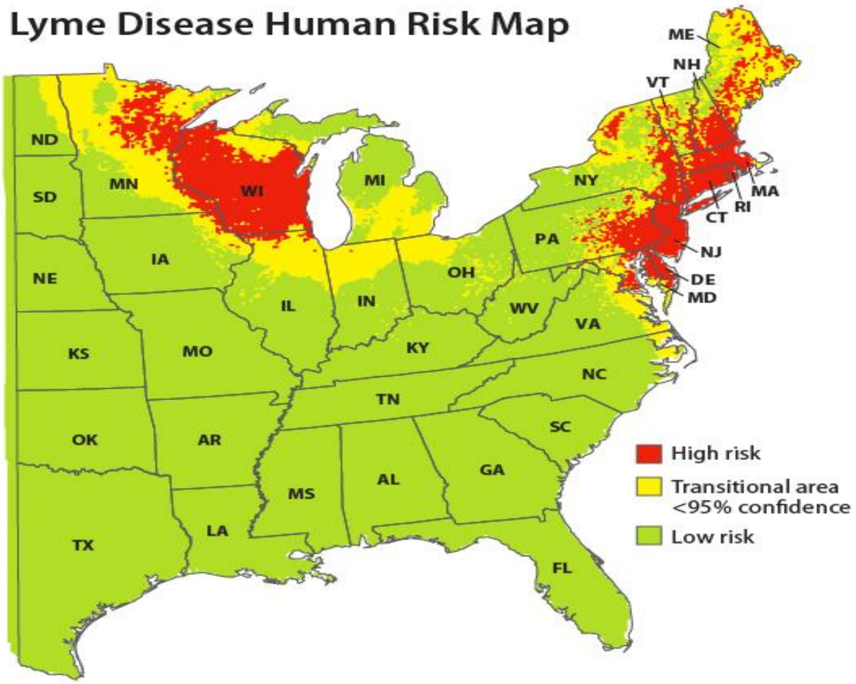


Predictive model for the Density of Nymphs (DON)

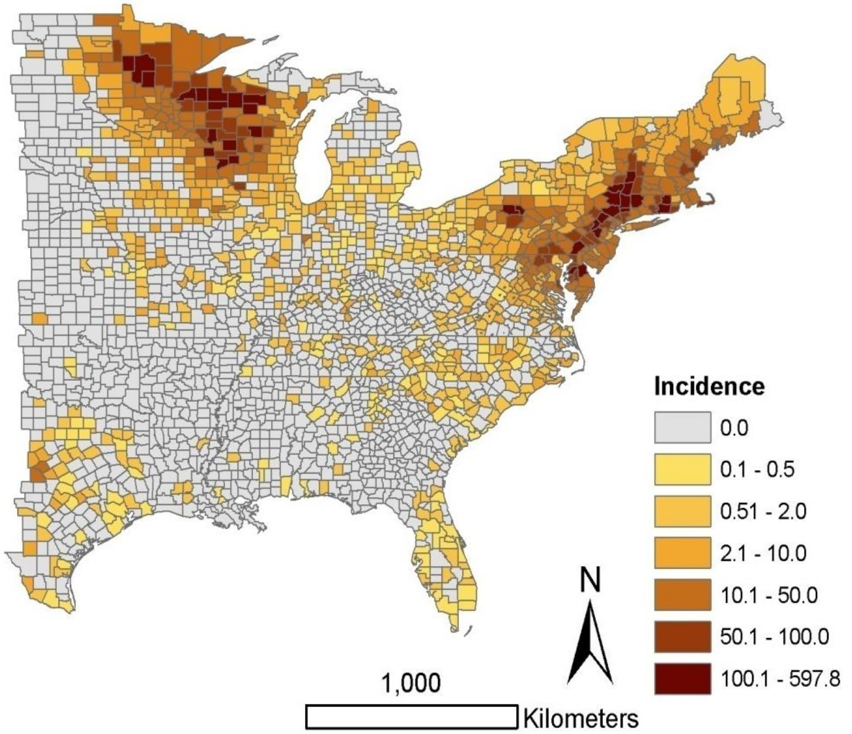
	Estimate	Std. Error	Prob>t
Zero-inflated			
Elevation	3.79	0.93	<0.001
Vapor pressure deficit, monthly mean	4.89	1.31	<0.001
Maximum Temp, annual amplitude^2	1.23	0.50	<0.05
Minimum Temp, annual phase^2	2.42	0.65	<0.001
Negative Binomial			
Autocovariate term	0.44	0.10	<0.0001
NDVI, annual amplitude^2	0.33	0.20	0.10

Sites correctly classified as positive/negative: 83%
Sensitivity: 89%
Specificity: 82%.

DIN is associated with the risk of Lyme disease in the United States (2004-2007)



Density of Infected *I. scapularis* nymphs



Lyme disease incidence/100,000 people

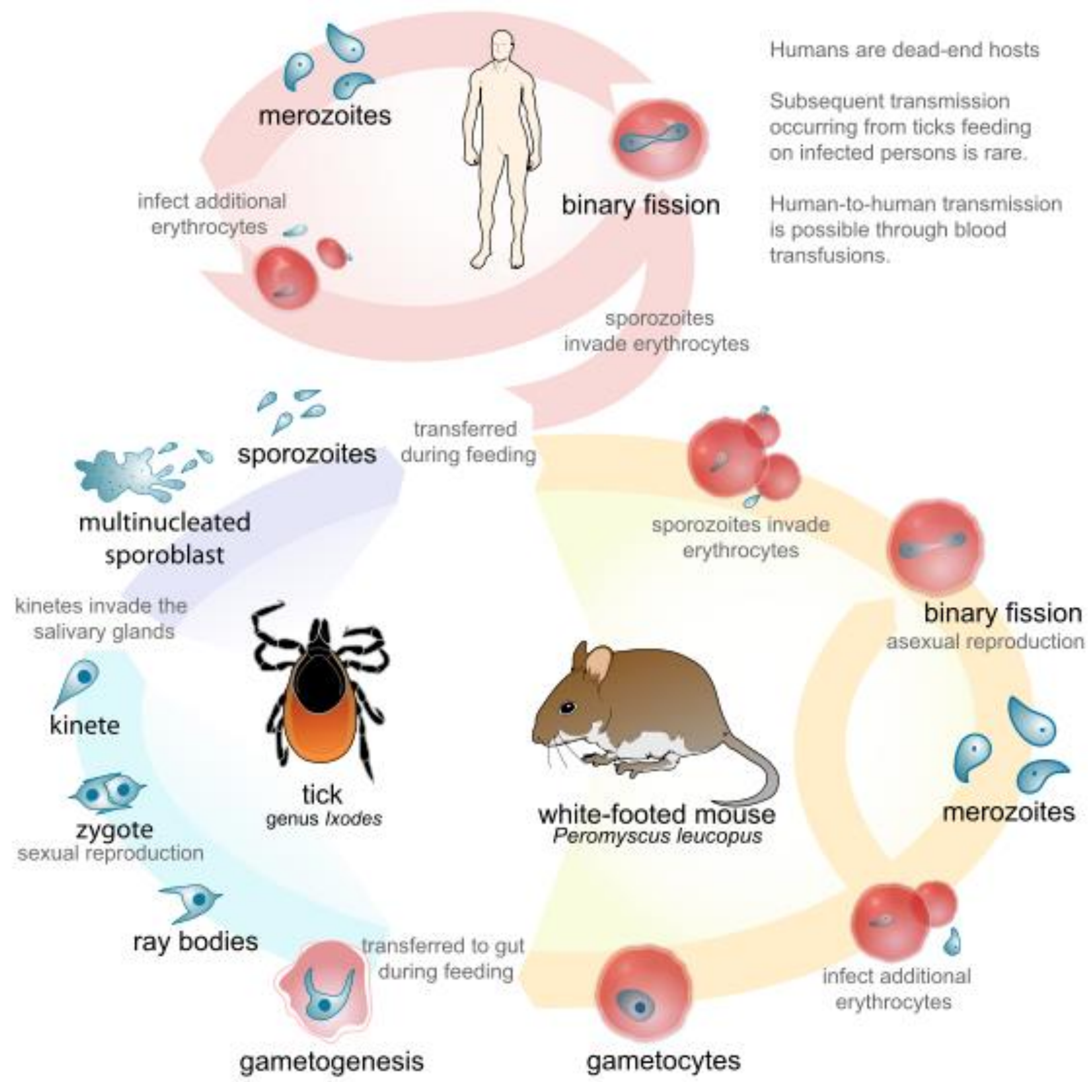
Diuk-Wasser et al., AJTMH, 2012

Pepin et al., AJTMH, 2012

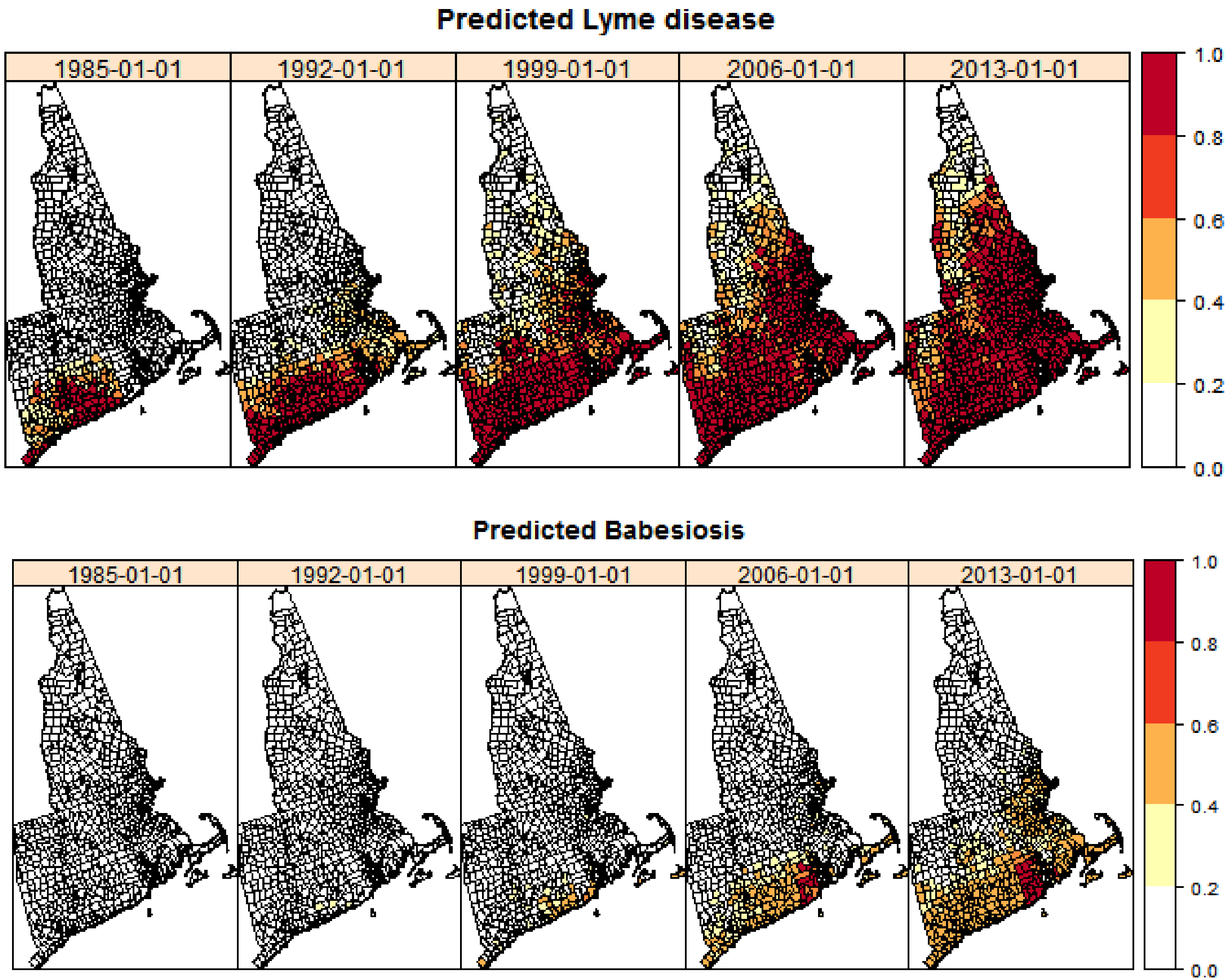
Seasonality

Effect on pathogen life cycle and diversity

Babesia microti: A malaria-like parasite transmitted by *Ixodes scapularis*

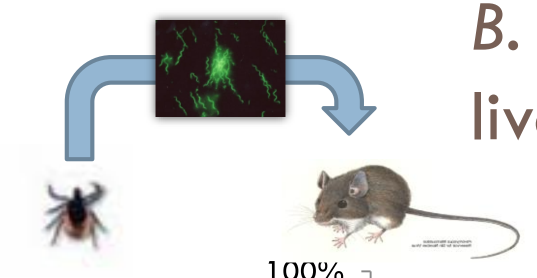


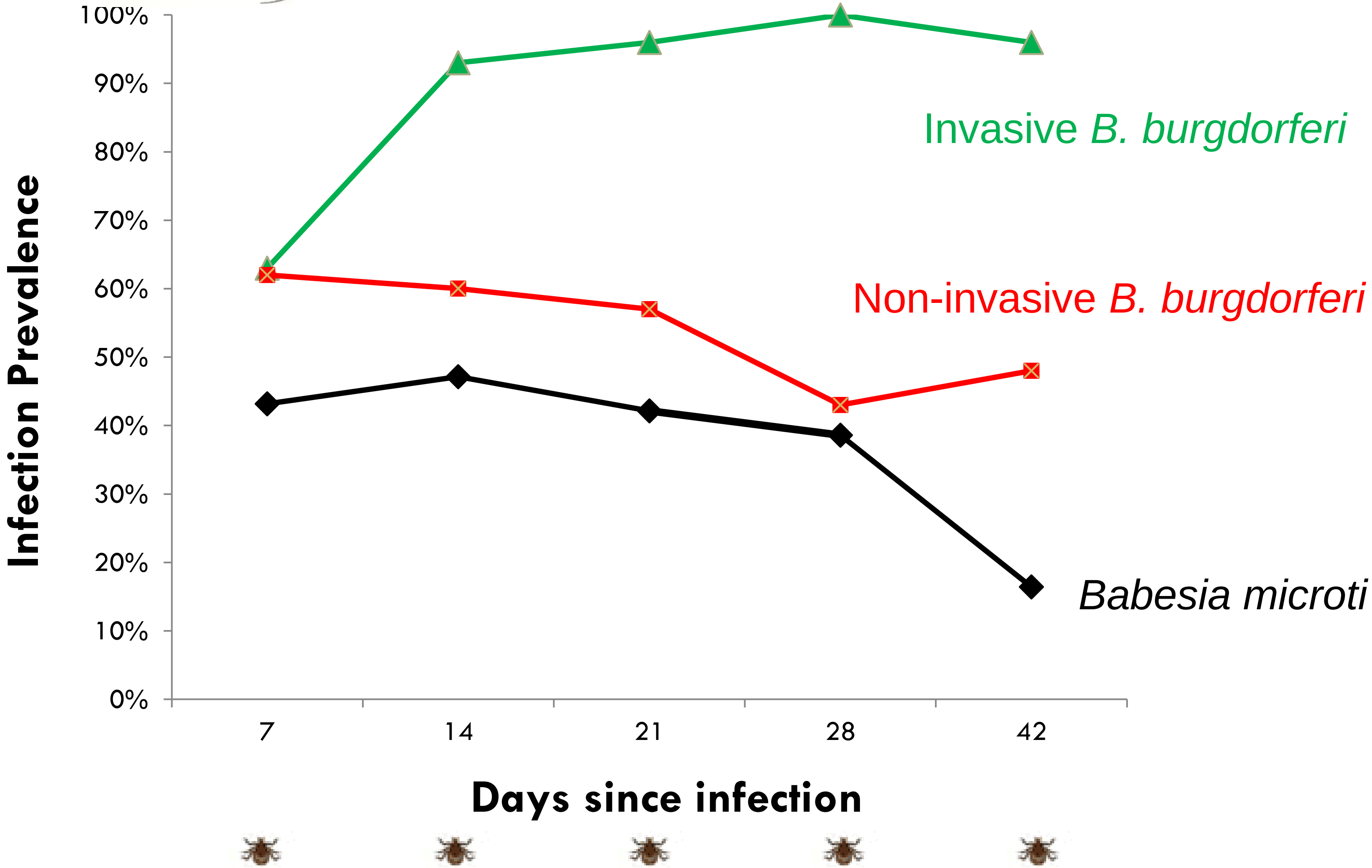
Geoographic spread of babesiosis lags behind Lyme disease



Katherine Walter

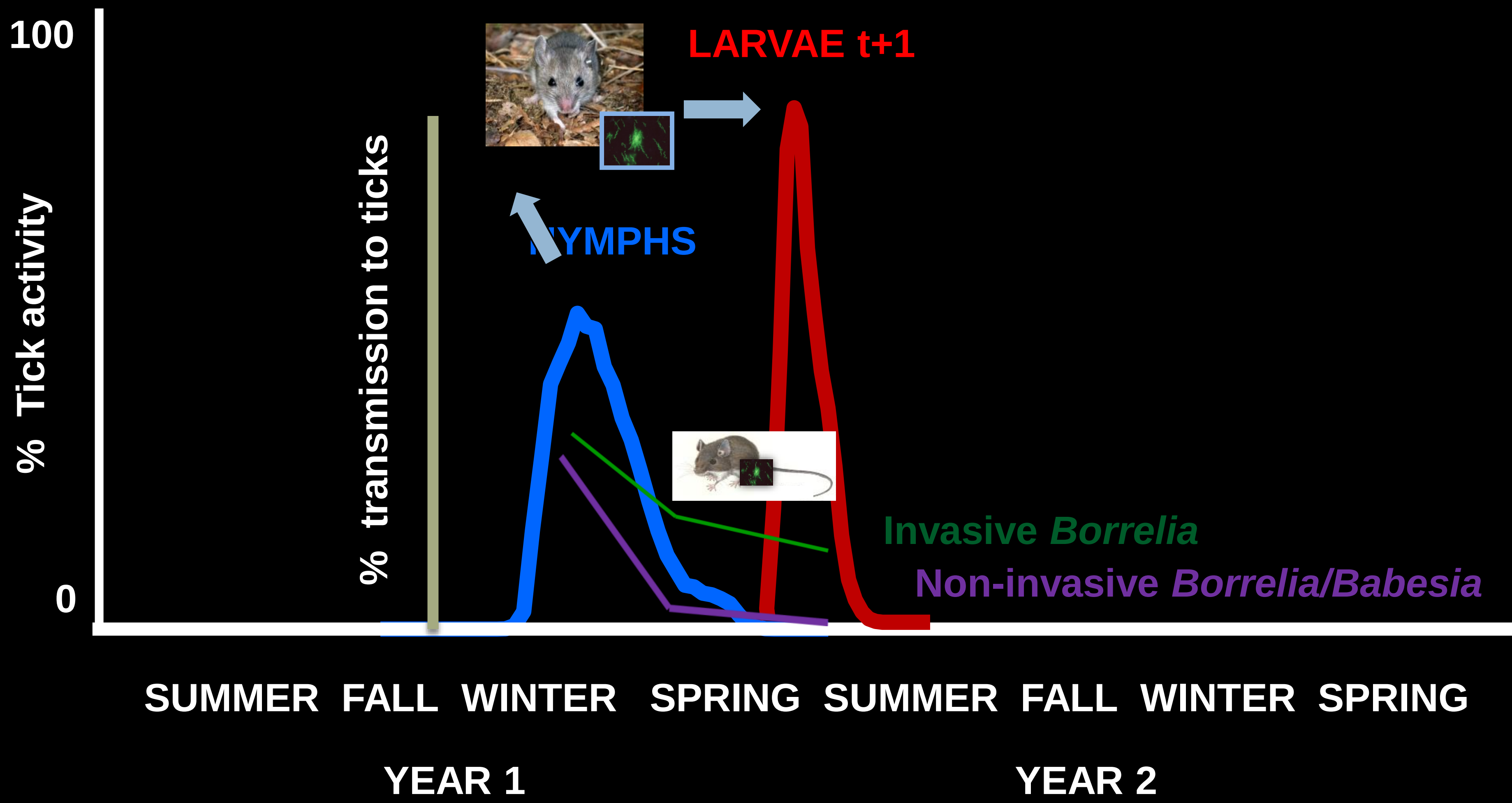
Pathogens other than *B. burgdorferi* as well as *B. burgdorferi* non-invasive strains are short lived in white-footed mice



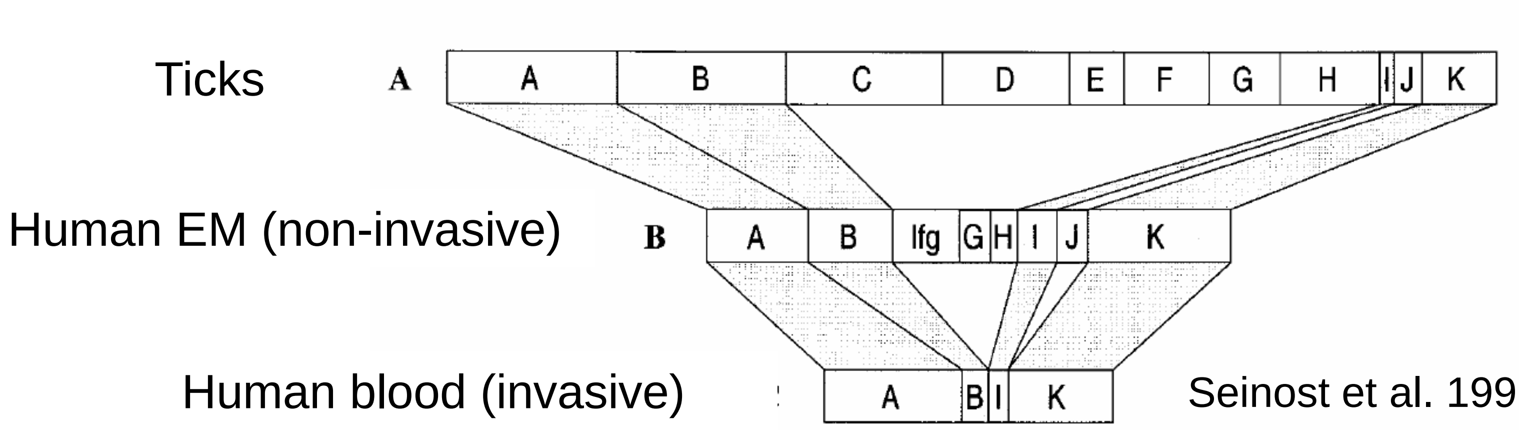


Synchronous feeding

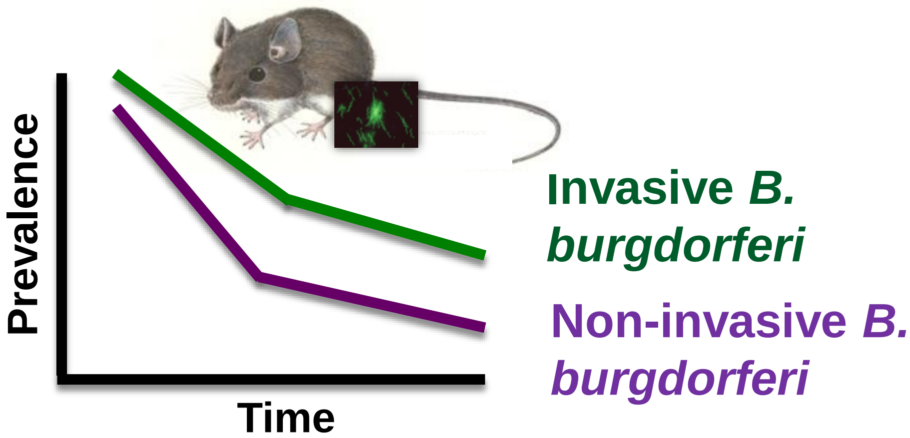
Asynchronous feeding



Parallel between persistence in white-footed mice and invasiveness in humans

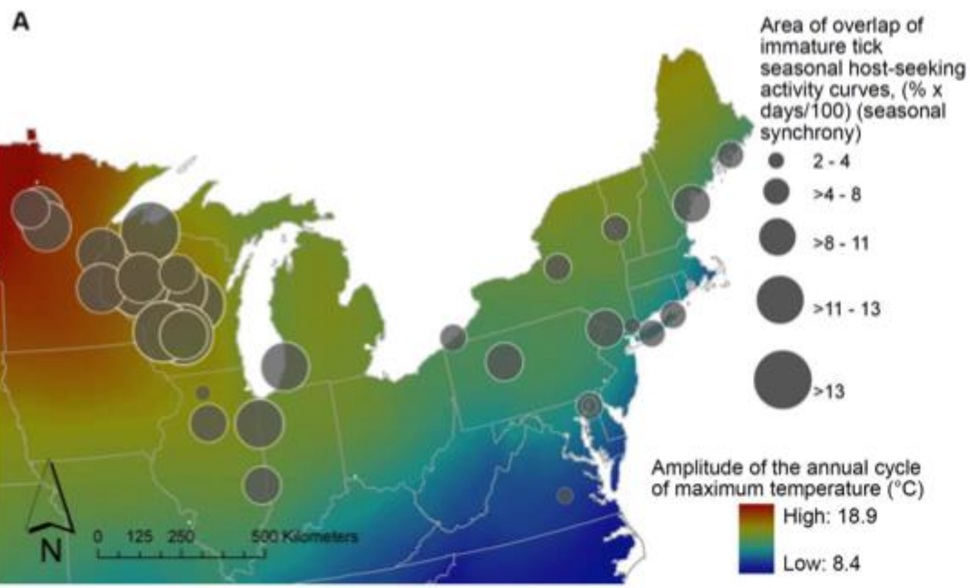


Seinost et al. 1999

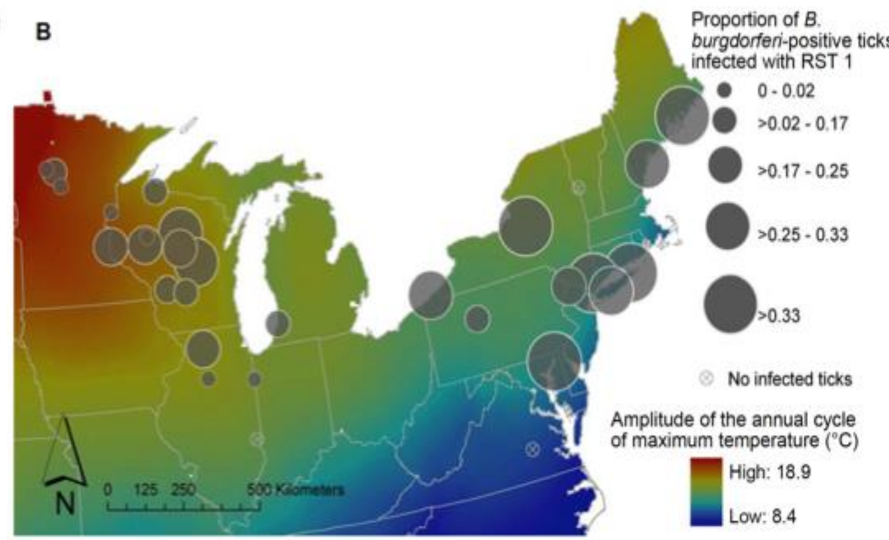


Prediction: Asynchronous tick feeding = higher frequency of mouse persistent and human invasive *Bb* genotypes

Nymphal/larval synchrony



Frequency of invasive genotypes

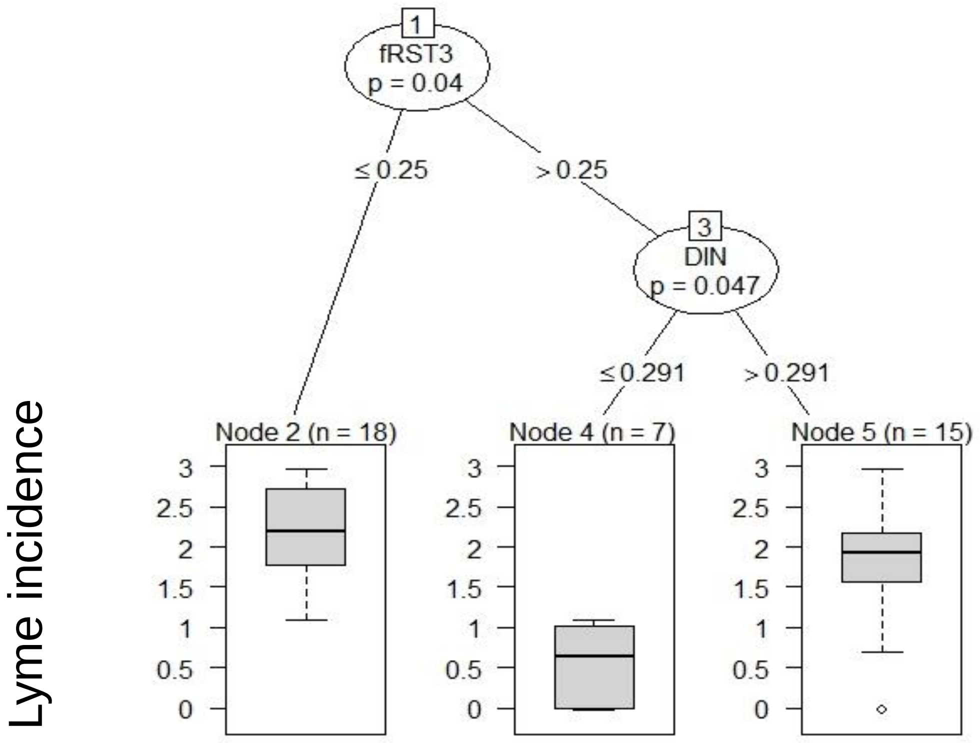


Does this explain why there is higher incidence of Lyme disease in the Northeast than the Midwest?

Gatewood et al. 2009, AEM

Frequency of *B. burgdorferi* genotypes influences Lyme disease incidence more than the density of infected nymphs

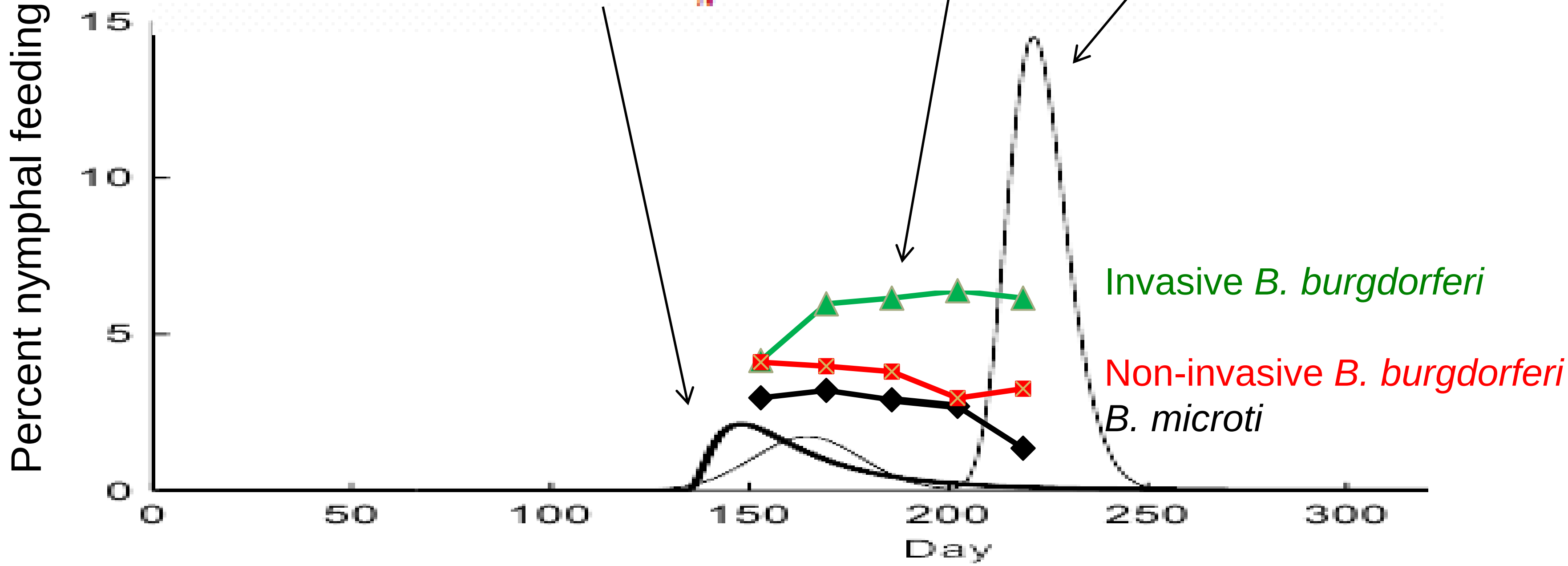
Frequency of non invasive genotypes



Pepin et al., AJTMH, 2012

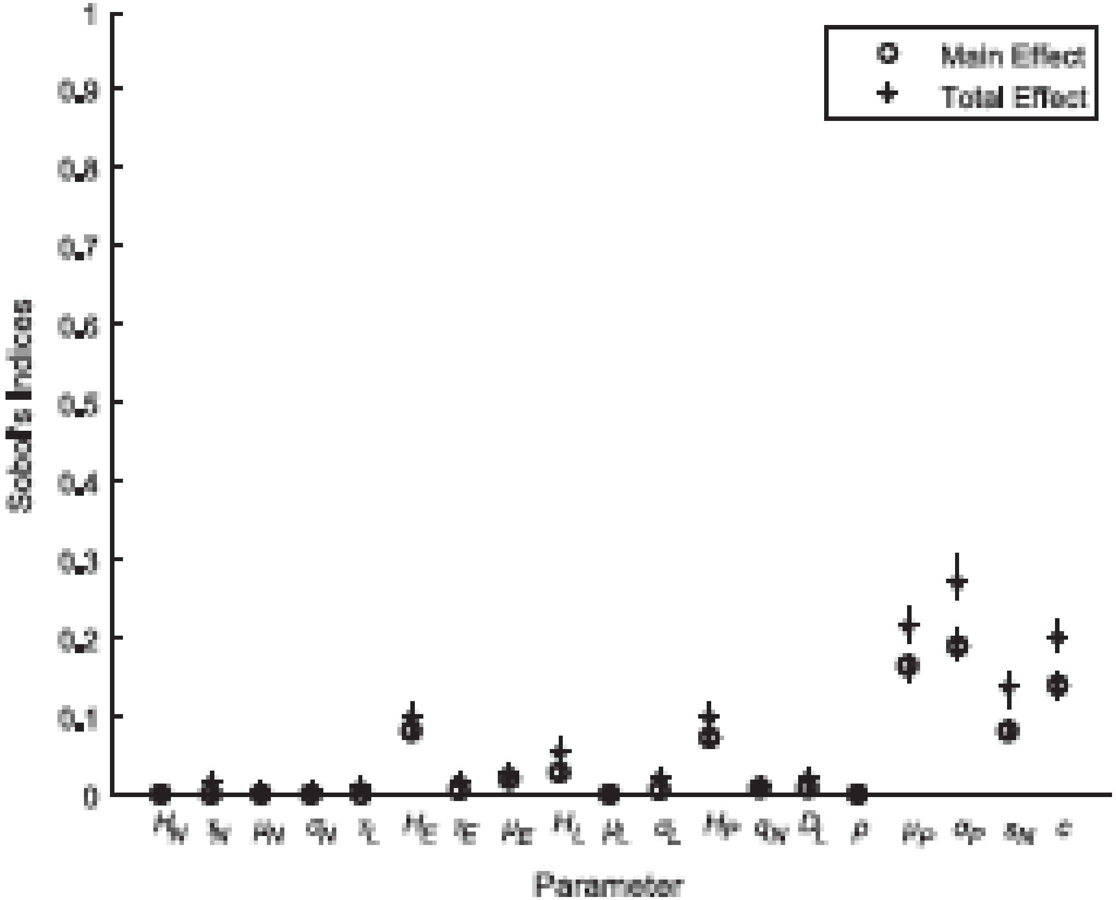
Modeling pathogen establishment accounting for tick seasonality and pathogen dynamics

$$R_0 = \sqrt{s_N\, q_N \underbrace{\int_{t=0}^{t=365} a_N(t)}_{\text{The proportion of host seeking nymphs of } Z_N} \underbrace{\int_{t'=0}^{t'=365-t} \frac{1}{d_L}\, p(t')\, \theta^{t'}\, \bar{Z}_L(t'+t)\, dt'\, dt}_{\text{Number of larvae infected by a mouse}}}$$



Dunn et al. 2013

Global sensitivity analysis



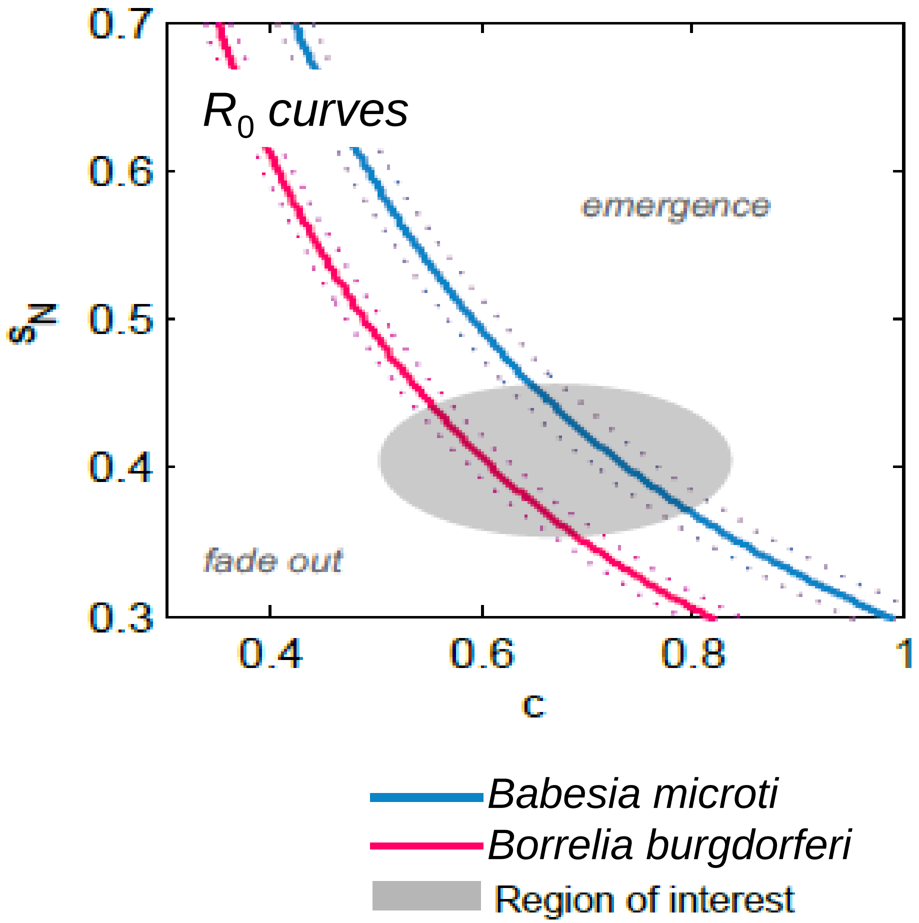
Most influential parameters

s_N = larval survivorship to feeding nymph

c = probability of finding a competent host

Timing of peak and duration of infectivity in mice, with strong interaction with phenology parameters

B. burgdorferi can persist in more ‘stringent’ ecological conditions than *B. microti*



s_N = larval survivorship
c = probability of finding a competent host

Conclusions

- Vapor pressure deficit is a limiting factor for *I. scapularis* distribution and can regulate host-seeking behavior.

- Lower temperatures may limit *I. scapularis* distribution by reducing overwintering survivorship and lengthening tick life cycle.

- The frequency of invasive vs non invasive *B. burgdorferi* genotypes is associated with tick phenology, in turn influenced by temperature seasonality.

- Climatic conditions in the Upper Midwest and certain locations/years in the Northeast favor the transmission of *I. scapularis*-borne pathogens with short lived infections in the host, such as *B. microti* and Powassan virus. Emergence hot spot?

Research needs: Tick natural history
'To seek or not to seek'

- What drives the timing of tick developmental diapause: photoperiod vs temperature?
  - Genetically determined or plastic?

- What's a tick's optimal foraging behavior?

Based on:
  - Differential temperature and vapor pressure deficit in the air and leaf litter
  - Probability of encountering a host: host and tick abundance and host movement
  - Tick fat reserves

Thanks!

Yale School of Public Health
Durland Fish
Peter Krause

Anne Gatewood
Tanner Steeves
Corrine Folsom-O'Keefe

Sarah States
Giovanna Carpi
Katharine Walter

Lindsay Rollend
Stephen Bent
Mohammed Salim
Casey Finch
Gwenael Vourc'h
Sahar Usmani-Brown

>20 MPh and undergraduate students
>100 Field assistants

Michigan State University
Jean Tsao
Sarah Hamer
Graham Hickling

University of Illinois
Uriel Kitron
Roberto Cortinas
Michelle Rowland

U. Calif Irvine.
Alan Barbour

Yale Center for Earth Observation
Roland Geerken
Larry Bonneau
Ronald Smith

Yale EPH Biostatistics Division
Paul Cislo
Theodore Holford
Yongtao Guan

NASA Ames - Forrest Melton

Royal Melbourne Institute of Technology
Stephen Davis
Jessica Dunn

Colorado State University
Kim Pepin

Royal Melbourne Institute of Technology
Stephen Davis
Jessica Dunn

FUNDERS

CENTERS FOR DISEASE CONTROL AND PREVENTION
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NATIONAL INSTITUTES OF HEALTH