Beating the Heat, and Fighting the Bite: Climate Change, Lyme Disease, and other Vector-borne Diseases in Vermont
Lyme Disease

- Infection with *Borrelia burgdorferi* spirochetes
- First identified in 1976 – Lyme, CT
- Transmitted by *Ixodes* ticks
- Reported case counts have been increasing

From CDC 2016,
http://www.cdc.gov/ticknet/images/ixodesscapularis.jpg

From CDC 2016,
http://www.cdc.gov/dotw/lyme-disease/index.html
Lyme disease symptoms

- “Classic” erythema migrans rash
- Facial palsy
- Swollen knee
Reported Cases of Lyme Disease—United States, 2014

One dot is placed randomly within the county of residence for each confirmed case. Though Lyme disease cases have been reported in nearly every state, cases are reported based on the county of residence, not necessarily the county of infection.

1 dot placed randomly within county of residence for each confirmed case.
Epidemiology of Lyme Disease


- Confirmed cases
- Probable cases*
Epidemiology of Lyme Disease

Confirmed and Probable Lyme Disease Cases 1999 – 2015
(Probable cases added after 2007)
Geographic Trend of Lyme
Black-legged Ticks

- 2-year life cycle
- 4 life stages
  - Egg, larva, nymph, adult
- Pathogens can be transmitted by infected adult females and nymphs
Black-legged ticks – Life Cycle
Black-legged ticks – Life Cycle
Seasonality of Lyme Disease

Monthly Vermont Lyme Disease Cases, 2014

- Probable
- Confirmed
But wait ... there's more.
Anaplasmosis

- *Anaplasma phagocytophilum*
- Transmitted by *Ixodes* ticks
- Incidence of reported cases is rising

**Symptoms**

- Fever, chills, sweats, head, muscle aches
- Up to 1/3 of cases hospitalized in VT
- Treatable with antibiotics

[Image: http://www.cdc.gov/anaplasmosis/images/modules/flash/Morulae_355px.jpg]
Anaplasmosis

Anaplasmosis Incidence, 2010

Cases per million

- NN
- 0
- 0.1-0.7
- 0.7-3.1
- >3.1
Anaplasmosis

Vermont Confirmed Anaplasmosis Cases, 2010 - 2015

- 2010: 3 cases
- 2011: 10 cases
- 2012: 17 cases
- 2013: 37 cases
- 2014: 67 cases
- 2015: 138 cases
## Tick-borne diseases of concern

<table>
<thead>
<tr>
<th>Disease</th>
<th>Pathogen</th>
<th>Cases in Vermont in last 10 years?</th>
<th>Black-legged tick</th>
<th>Woodchuck tick</th>
<th>Lone star tick</th>
<th>American dog tick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyme Disease</td>
<td><em>Borrelia burgdorferi</em></td>
<td>Yes</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anaplasmosis</td>
<td><em>Anaplasma phagocytophilum</em></td>
<td>Yes</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Babesiosis</td>
<td><em>Babesia microti</em></td>
<td>No</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Powassan</td>
<td>Powassan Virus (POWV) / Deer Tick Virus (DTV)</td>
<td>No</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erlichiosis</td>
<td><em>Erlichia spp.</em></td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Rocky Mountain Spotted Fever</td>
<td><em>Rickettsia rickettsia</em></td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Tularemia</td>
<td><em>Franciscella tularensis</em></td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
The Role of Climate Change
“Climate change is not going to invent any new diseases; it's going to make controlling existing diseases harder.”

Diarmid Campbell-Lendrum,
World Health Organization (WHO)
How climate change affects tick-borne diseases

Altitude
Latitude
Abundance
# How climate change may affect tick-borne diseases

## Mechanisms

<table>
<thead>
<tr>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alter tick survival and reproduction</td>
</tr>
<tr>
<td>Alter pathogen survival in hosts</td>
</tr>
<tr>
<td>Phenology: Changing the timing of developmental cycles of tick larvae,</td>
</tr>
<tr>
<td>nymphs, and adults, affecting the seasonality of disease</td>
</tr>
<tr>
<td>Change reservoir host behavior (e.g. deer and mice)</td>
</tr>
<tr>
<td>Change human behavior</td>
</tr>
</tbody>
</table>
Ogden and others (2014) suggest that:

- "Areas that are at present climatically unsuitable as deer tick habitat may become infested in the future"

- "In regions already suitable but not yet infested, the rate of invasion will be accelerated"

- "Tick abundance may increase in areas where the ticks are already present"
Question

Are there meteorological and environmental factors that might explain the geographic distribution of Lyme disease incidence in Vermont?

Can these help explain how climate change may affect Lyme disease?
Methods - Data

- Lyme disease cases
  - January 2005 – October 2014
  - Daily case reports
  - All cases included
  - Aggregated to 87 sub-county geographies (towns and groups of towns)
    - Log-normalized incidence rates
- Median elevation
- Median latitude
- Percent forest cover
Methods - Data

Current Meteorological Data

PRISM Climate Group – Oregon State University

Baseline data: 1981 – Present
Daily data – Precipitation & Temperature
4 km resolution
Aggregated to county and state-wide by VT Climatologist’s Office

County-Level Associations

10-Year Crude Incidence of Lyme Disease by Seasonal Precipitation

- **Average Winter precipitation (inches)**
- **Average Spring precipitation (inches)**
- **Average Summer precipitation (inches)**
- **Average Fall precipitation (inches)**

Cases per 100k persons per year:

- 1
- 10
- 100
- 1000
County-Level Associations

10-Year Crude Incidence of Lyme Disease by Seasonal Temperature

- **Average Winter Temperature (°F)**
  - Cases per 100k persons per year:
    - 1 to 10
    - 10 to 100
    - 100 to 1000

- **Average Spring Temperature (°F)**
  - Cases per 100k persons per year:
    - 1 to 10
    - 10 to 100
    - 100 to 1000

- **Average Summer Temperature (°F)**
  - Cases per 100k persons per year:
    - 1 to 10
    - 10 to 100
    - 100 to 1000

- **Average Fall Temperature (°F)**
  - Cases per 100k persons per year:
    - 1 to 10
    - 10 to 100
    - 100 to 1000
County-Level Associations

10-Year Crude Incidence of Lyme Disease by Seasonal Temperature

- **Average Winter Temperature (°F)**
- **Average Fall Temperature (°F)**
- **Average Spring Temperature (°F)**
- **Average Summer Temperature (°F)**

Cases per 100k persons per year.
County-Level Associations

10-Year Crude Incidence of Lyme Disease by Average Winter Temperature

<table>
<thead>
<tr>
<th>β</th>
<th>P-value</th>
<th>Adj. $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.498</td>
<td>&lt;.0001</td>
<td>0.7806</td>
</tr>
</tbody>
</table>
Sub-county Lyme Disease Incidence

Vermont Lyme Disease Incidence 2005 - 2014, Adjusted for Age and Sex

Legend
- Counties
- Lake Champlain
- Suppressed - Fewer than 6 total cases

Cases per 100k persons, per year
- 0.0 - 27.3
- 27.4 - 62.5
- 62.6 - 116.6
- 116.7 - 209.9
- 210.0 - 427.2
Sub-county Lyme Disease Incidence
Linear Regression Models

Dependent Variable

- Log-normalized, age and sex-adjusted incidence rates, 2005-2014

Independent Variables

- Sub-county Level:
  - Median latitude
  - Median elevation
  - Percent forest canopy coverage

- County Level:
  - Average seasonal temperature & precipitation
  - Average GDD, HDD, CDD
### Preliminary Results

<table>
<thead>
<tr>
<th>Covariate (adjusted for latitude, elevation, forest cover)</th>
<th>Parameter Estimate</th>
<th>P-value</th>
<th>Adj. Model R²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seasonal Temperature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg_Fall_Temp</td>
<td>0.22990</td>
<td>0.0114</td>
<td>0.6747</td>
</tr>
<tr>
<td>Avg_Summer_Temp</td>
<td>0.09686</td>
<td>0.2160</td>
<td>0.6552</td>
</tr>
<tr>
<td>Avg_Spring_Temp</td>
<td>0.16352</td>
<td>0.0609</td>
<td>0.6633</td>
</tr>
<tr>
<td>Avg_Winter_Temp</td>
<td>0.24847</td>
<td>0.0063</td>
<td>0.6788</td>
</tr>
<tr>
<td><strong>Seasonal Precipitation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg_Fall_Precip</td>
<td>-0.10454</td>
<td>0.4118</td>
<td>0.6517</td>
</tr>
<tr>
<td>Avg_Summer_Precip</td>
<td>-0.10503</td>
<td>0.4982</td>
<td>0.6508</td>
</tr>
<tr>
<td>Avg_Spring_Precip</td>
<td>0.03311</td>
<td>0.7853</td>
<td>0.6491</td>
</tr>
<tr>
<td>Avg_Winter_Precip</td>
<td>-0.07969</td>
<td>0.5275</td>
<td>0.6505</td>
</tr>
</tbody>
</table>
## Preliminary Results

<table>
<thead>
<tr>
<th>Covariate (adjusted for latitude, elevation, forest cover)</th>
<th>Parameter Estimate</th>
<th>P-value</th>
<th>Adj. Model $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seasonal Temperature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg_Fall_Temp</td>
<td>0.22990</td>
<td>0.0114</td>
<td>0.6747</td>
</tr>
<tr>
<td>Avg_Summer_Temp</td>
<td>0.09686</td>
<td>0.2160</td>
<td>0.6552</td>
</tr>
<tr>
<td>Avg_Spring_Temp</td>
<td>0.16352</td>
<td>0.0609</td>
<td>0.6633</td>
</tr>
<tr>
<td>Avg_Winter_Temp</td>
<td>0.24847</td>
<td>0.0063</td>
<td>0.6788</td>
</tr>
<tr>
<td><strong>Seasonal Precipitation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg_Fall_Precip</td>
<td>-0.10454</td>
<td>0.4118</td>
<td>0.6517</td>
</tr>
<tr>
<td>Avg_Summer_Precip</td>
<td>-0.10503</td>
<td>0.4982</td>
<td>0.6508</td>
</tr>
<tr>
<td>Avg_Spring_Precip</td>
<td>0.03311</td>
<td>0.7853</td>
<td>0.6491</td>
</tr>
<tr>
<td>Avg_Winter_Precip</td>
<td>-0.07969</td>
<td>0.5275</td>
<td>0.6505</td>
</tr>
</tbody>
</table>
Preliminary Results

- Areas with warmer winters have had higher incidence of Lyme disease over the last 10 years.
  - Tick overwintering survival
  - White-footed mouse overwintering survival

- Next Steps:
  - Examining year-by-year associations,
  - Incorporating lag times into the model
Moving Forward

- Tick and pathogen surveillance
- Continue Lyme prevention messaging
- Collaborate with other states!
- Communicate health issues to climate professionals
- Include climate change in health messaging!
Education & prevention

- Awareness of risk
- Tick identification
- Disease transmission
- Prevention
  - While outdoors
  - After coming indoors
- Tick removal
- Symptoms
- When to seek treatment
Contact information:
Nate Schafrick
Epidemiologist, Climate & Health Program
Vermont Dept. of Health
nathaniel.schafrick@vermont.gov
ClimateHealth@vermont.gov
802-951-0174