Tick Biology and Ecology
Outline of presentation

- Overview (J Piesman)
- Tularemia (L Eisen)
- GIS (RJ Eisen)

Group Members: J Piesman, CDC; RJ Eisen, CDC; L Eisen, CSU; C Apperson, NC State; U Kitron, Emory; L Durden, GA Southern; D Gaines, VA Dept Hlth; G Hickling, Univ TN
Figure 2. Adult Female *Amblyomma americanum* (Lone Star Tick), Adult Female and Nymphal *Ixodes scapularis* (Deer Ticks), and Adult Female *Dermacentor variabilis* (Dog Tick).
Amblyomma americanum

- Extremely dense populations in forested areas of eastern US
- All 3 stages focused on deer; may feed on birds occasionally, not rodents
- All three stages bite humans aggressively in the southern US
- Human pathogen transmission: *Ehrlichia chaffeensis* (HME)
- Other associated organisms of interest: *Rickettsia amblyommii*, *Borrelia lonestari*
**Dermacentor variabilis**

- Associated with “old field” habitat
- Adult stages focused on domestic dogs (other medium sized mammals too), immatures on rodents (e.g. voles)
- Only adults (males and females) feed on people
- Human pathogen transmission: *Rickettsia rickettsii*
- Other associated organisms of interest: Numerous spotted-fever rickettsia
Ixodes scapularis

- Forested habitat throughout eastern US
- Populations denser in northern US than southern US
- Adults focused on deer, immatures on rodents, birds, lizards
- In northern US all 3 stages bite people; in southern US mainly adults found on people
- Human pathogens of interest: *Borrelia burgdorferi*, *Anaplasma phagocytophilum*, *Babesia microti* (northern US only?)
- Other associated organisms of interest: *Borrelia miyamotoi* s.l., Rickettsial symbiont, deer tick virus, *Babesia odocoilei*
Ambylomma americanum publications by year
Dermacentor variabilis publications by year
Ixodes scapularis publications by year
Ixodes dammini* publications by year
Personal experience with tick populations in the south (J Piesman)

- 4 years on faculty School of Public Health, University Alabama Birmingham (1985-1989; field work throughout state of Alabama & Land Between the Lakes, KY)
- 1 week collecting on barrier islands (Sapelo & St. Catherine’s) off the coast of Georgia
- 1 week collecting w Jerome Goddard near Jackson, MS
- 1 week collecting along VA-MD border w D Sonenshine
- Several weeks collecting A. americanum on military facilities in Missouri (e.g. Ft. Leonardwood)
Observations on southern ticks (J Piesman)

- *A. americanum* are all over the place
- Majority of deer are infested with *I. scapularis* in the winter, but populations not as dense as up north
- Immature *I. scapularis* (especially nymphs) difficult to flag from vegetation and rarely infest people
- Lizards are abundant in some locations* and heavily infested with immature *I. scapularis*
- Rodent populations are not dense, they are difficult to trap, and rarely infested with *I. scapularis*
- Seasonal cycle of *I. scapularis* in south different from northern populations
Table 1. Immature ticks collected by drag cloth or flag, Copiah County Wildlife Management Area, MS, 2005-2006.

<table>
<thead>
<tr>
<th>Date</th>
<th>Method</th>
<th>Drag cloth hours</th>
<th># AA nymphs</th>
<th># DV nymphs</th>
<th># IS larvae</th>
<th># IS nymphs</th>
<th>Total # ticks/hr</th>
<th># Immature IS/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 May 05</td>
<td>Flag¹</td>
<td>1.0</td>
<td>51</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>52</td>
<td>1</td>
</tr>
<tr>
<td>27 May 05</td>
<td>Flag</td>
<td>1.0</td>
<td>77</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>77</td>
<td>0</td>
</tr>
<tr>
<td>13 June 05</td>
<td>Flag</td>
<td>1.0</td>
<td>53</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>61</td>
<td>8</td>
</tr>
<tr>
<td>14 June 05</td>
<td>Flag</td>
<td>1.0</td>
<td>20</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>24</td>
<td>4</td>
</tr>
<tr>
<td>14 Apr 06</td>
<td>Flag</td>
<td>1.0</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>18 Apr 06</td>
<td>Flag ²</td>
<td>2.0</td>
<td>20²</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>18 Apr 06</td>
<td>Drag³</td>
<td>4.0</td>
<td>80²</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>20</td>
<td>0.25</td>
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<tr>
<td>19 Apr 06</td>
<td>Drag</td>
<td>6.0</td>
<td>200²</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>20 Apr 06</td>
<td>Drag</td>
<td>3.0</td>
<td>100²</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>33</td>
<td>0.33</td>
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<tr>
<td>28 Apr 06</td>
<td>Drag</td>
<td>1.0</td>
<td>65</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>66</td>
<td>0</td>
</tr>
<tr>
<td>11 May 06</td>
<td>Drag</td>
<td>1.0</td>
<td>41</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>42</td>
<td>0</td>
</tr>
<tr>
<td>16 May 06</td>
<td>Flag</td>
<td>2.0</td>
<td>73</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>37</td>
<td>0</td>
</tr>
<tr>
<td>22 May 06</td>
<td>Flag</td>
<td>2.0</td>
<td>42</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>2 Jun 06</td>
<td>Flag</td>
<td>1.0</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>13 Jun 06</td>
<td>Flag</td>
<td>1.0</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>19 Jun 06</td>
<td>Flag</td>
<td>1.0</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>16</td>
<td>0</td>
</tr>
</tbody>
</table>

¹30 x 45 cm flag on mop handle.
²Estimated.
³1m² standard drag cloth.
Cumulative probability of infected *I. scapularis* transmitting *B. burgdorferi* for each hour attached

Figure 1. Cumulative probability of infected *Ixodes scapularis* field-collected nymphs transmitting *Borrelia burgdorferi* over measured durations of attachment.

des Vignes et al. 2001 J Infect Dis 183: 773-778
Tick Dragger: Worst Science Jobs

Go to remote, densely overgrown forest. Take out giant white corduroy sheet. Drag it behind you as you sing loudly to ward off bears. After 20 meters, stop. Do not tarry to smack mosquitoes, for you must immediately tweezer several hundred tiny potentially Lyme disease carrying ticks that have covered both you and your white cloth, and drop them into a jar. Repeat 50 times a day. No this is not the instruction set for hell week at Phi Delta Sade. It’s the protocol for a study assessing Lyme disease risk across the eastern U.S., headed by Yale University epidemiologist Durland Fish.

From Popular Science Nov 2004
2004/2005 Sampling Sites

Data by M Diuk-Wasser, Yale Univ. & Risk Map Study Group
Predicted nymphal density
Questions regarding Big 3?

✿ *A. americanum*: Transmission of other agents besides HME, control for disease prevention (not as pest-TVA) practical, 4-poster?

✿ *D. variabilis*: RMSF increases in NC and elsewhere real? Ecology neglected? Main tularemia vector?

✿ *I. scapularis*: Population genetics, southern populations behavioral differences from northern populations, low infection rates w Bb due to biotic or abiotic factors?
Other ticks of interest

- *Amblyomma maculatum*: vector of *R. parkeri*
- *Rhipicephalus sanguineus*: Transmits *R. rickettsii* in AZ. Southeastern US too?
- *Ixodes minor* & *Ixodes affinis*: enzootic vectors of Bbsl-human risk?
Tularemia in the south-central US
Reported cases of tularemia

FIGURE 2. Reported cases* of tularemia — United States, 1990–2000

Why care about tick-borne F. tularensis?

- *Francisella tularensis* is a NIAID Category A Priority Pathogen
- Tularemia is a potentially severe disease with 100+ cases per year in the U.S.
- Novel technology (genetic techniques, GIS) can be used to pursue old poorly answered questions
- There are strong indications that ticks account for most human exposure to *F. tularensis* in the primary U.S. tularemia focus (AR-MO)
- We do not know which tick species and life stages serve as the primary vector(s) of *F. tularensis* to humans in the primary U.S. tularemia focus (AR-MO)
Tularemia cases, 1924 - 1948

8 States with >1,000 cases
8 States with > 500 cases

Source: Jellison 1974 Monograph
Annual tularemia cases in the U.S., 1944 - 2000

Source: Feldman 2003, JAVMA 222: 725-730
Change in the percentage of national tularemia cases reported by Arkansas-Missouri over time

Sources: Jellison 1974; Brooks and Buchanan 1970; Cox and Everett 1981; CDC 2002, 2005
Change in annual tularemia case load from 1924-48 to 2000-03 in Arkansas-Missouri vs. the rest of the U.S.
Change in annual tularemia case load from 1924-48 to 2000-03 in Arkansas-Missouri vs. the rest of the U.S.

Why has tularemia not faded away in Arkansas-Missouri?

- Rabbit exposure is still common in AR-MO

- AR-MO tularemia was historically associated primarily with tick-bites
Rabbit exposure still common in AR-MO?

Probable source of exposure in Arkansas, 1978-82

McChesney et al. 1983, J Ark Med Soc 80, 257-262
AR-MO tularemia was historically associated primarily with tick-bites?

Probable source of exposure in various States, 1924-51

% of cases

AR, 38-48
MO, 47-51
CA, 27-51
IL, 1938
IN, 24-48
LA, 28-44
WI, 24-48

Tick-bite
Lagomorph

FIGURE 2. Reported cases* of tularemia — United States, 1990–2000

Number of Cases

Yellow indicates approximate distribution area

Amblyomma americanum

Dermacentor variabilis

Ixodes scapularis
# Tick infestation, Arkansas

## TABLE III


<table>
<thead>
<tr>
<th>Rating of Tick Infestation</th>
<th>Number of Tick Bites</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;10</td>
<td>10–24</td>
</tr>
<tr>
<td>Nonexistent</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>(No problem exists)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slight</td>
<td>183</td>
<td>2</td>
</tr>
<tr>
<td>Moderate</td>
<td>233</td>
<td>51</td>
</tr>
<tr>
<td>Bad</td>
<td>158</td>
<td>102</td>
</tr>
<tr>
<td>Extremely bad</td>
<td>41</td>
<td>53</td>
</tr>
</tbody>
</table>

Tick bites over 6 mo period

Goddard 1992, Military Medicine 155, 277-280
Peak tick activity periods in relation to monthly tularemia cases, AR 1994-1998

Various sources
Which tick species and life stages most commonly bite humans in the primary U.S. tularemia focus (AR-MO)?

Merten and Durden 2000, J Vector Ecol 25, 102-113

AR: 12 Aa (5 Ad, 5 N, 2L) 3 Dv (Ad) 5 Is (Ad)
MO: 4 Aa (N) 3 Dv (Ad) 1 Is (Ad)
Tick infection rates with *Francisella tularensis* from existing studies in AR-MO are curiously low

<table>
<thead>
<tr>
<th>State</th>
<th>Nymphs</th>
<th>Adults</th>
<th>Mixed stages</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amblyomma americanum</strong>; 0.04% (10 / 25,000)</td>
<td>0.02 (1/5630)</td>
<td>0.06 (2/3300)</td>
<td>0.09 (7/7956)</td>
<td>Calhoun 1955</td>
</tr>
<tr>
<td>AR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AR-MO-OK</td>
<td>0 (≈9000)</td>
<td></td>
<td></td>
<td>Hopla 1953</td>
</tr>
</tbody>
</table>

**Dermacentor variabilis; 0% (0 / 3,500)**

<table>
<thead>
<tr>
<th>State</th>
<th></th>
<th></th>
<th></th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR</td>
<td></td>
<td>0 (2627)</td>
<td></td>
<td>Calhoun 1955</td>
</tr>
<tr>
<td>AR-MO-OK</td>
<td>0 (&lt;1,000)</td>
<td></td>
<td></td>
<td>Hopla 1953</td>
</tr>
</tbody>
</table>
Reported infection rates with *Francisella tularensis* of *Dermacentor variabilis* in AR-MO are curiously low

<table>
<thead>
<tr>
<th>State</th>
<th>Adults</th>
<th>Stages</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA</td>
<td>0.7</td>
<td>(30 / 4246)</td>
<td>Goethert et al. 2004 (PCR)</td>
</tr>
<tr>
<td>SD</td>
<td>&gt;2.4</td>
<td>(8 / &lt; 336)</td>
<td>Markowski et al. 1985 (DFA)</td>
</tr>
<tr>
<td>MT</td>
<td>&gt;3.6</td>
<td>(8 / &lt; 225)</td>
<td>Schmid et al. 1983 (DFA)</td>
</tr>
<tr>
<td>KT-TN</td>
<td>0.8</td>
<td>(7 / 931)</td>
<td>Burgdorfer et al. 1974 (Stain)</td>
</tr>
<tr>
<td>SD</td>
<td>1.4</td>
<td>(8 / 575)</td>
<td>Saliba 1966 (Stain)</td>
</tr>
<tr>
<td>AR</td>
<td>0</td>
<td>(2627)</td>
<td>Calhoun 1955 (Inoculation)</td>
</tr>
<tr>
<td>NC-PA -VA</td>
<td>0</td>
<td>(536)</td>
<td>Parker 1952 (Inoculation)</td>
</tr>
<tr>
<td>AR-MO-OK</td>
<td>0</td>
<td>(&lt;1000)</td>
<td>Hopla 1953 (Inoculation)</td>
</tr>
<tr>
<td>MN</td>
<td>0.05</td>
<td>(1 / 2000)</td>
<td>Green 1931 (Inoculation)</td>
</tr>
</tbody>
</table>
Experimental studies of vector competency for Francisella tularensis

<table>
<thead>
<tr>
<th>Strain</th>
<th>F. tularensis biovar</th>
<th>Demonstration of Path.</th>
<th>Transst. Passage</th>
<th>Transmission</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amblyomma americanum</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schu (Sm)</td>
<td>Type A</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>Hopla 1953</td>
</tr>
<tr>
<td><strong>Dermacentor variabilis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>ND</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>Philip 1934</td>
</tr>
<tr>
<td>Vavenby</td>
<td>Type A</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>Bell 1945</td>
</tr>
<tr>
<td>Nevada 14, Schu, Vavenby</td>
<td>Type A</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>Bell 1979</td>
</tr>
<tr>
<td><strong>Ixodes scapularis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schu (Sm)</td>
<td>Type A</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>Hopla 1962</td>
</tr>
</tbody>
</table>

Transmission studies on Type B are entirely lacking
Key points

We do not know which tick species is the most important vector of the NIAID Priority A Pathogen *Francisella tularensis* in the primary U.S. tularemia focus

The roles of deer flies as vectors and various mammals as reservoirs of *Francisella tularensis* also remains unclear
Table 2
County unit-based associations between percentage coverage by different habitat types and tularemia incidence class, 1990–2003, in the south-central United States

<table>
<thead>
<tr>
<th>Habitat type*</th>
<th>Arkansas-Missouri (N = 190 counties)</th>
<th>Oklahoma-Kansas-Nebraska (N = 275 counties)</th>
<th>Illinois-Indiana-Kentucky-Tennessee (N = 409 counties)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Association with tularemia incidence class†‡</td>
<td>P</td>
<td>Association with tularemia incidence class†‡</td>
</tr>
<tr>
<td>Suitable habitat for vector ticks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry forest—all types combined</td>
<td>Positive</td>
<td>&lt; 0.001</td>
<td>Positive</td>
</tr>
<tr>
<td>Dry deciduous forest</td>
<td>Positive</td>
<td>0.02</td>
<td>Positive</td>
</tr>
<tr>
<td>Dry coniferous forest</td>
<td>Positive</td>
<td>0.02</td>
<td>Positive</td>
</tr>
<tr>
<td>Dry mixed forest</td>
<td>Positive</td>
<td>&lt; 0.001</td>
<td>Positive</td>
</tr>
<tr>
<td>Partially suitable habitat for vector ticks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrubland</td>
<td>None</td>
<td>0.10</td>
<td>None</td>
</tr>
<tr>
<td>Grassland (including pasture)</td>
<td>Positive</td>
<td>0.03</td>
<td>None</td>
</tr>
<tr>
<td>Urban</td>
<td>None</td>
<td>0.24</td>
<td>None</td>
</tr>
<tr>
<td>Unsuitable habitat for vector ticks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>None</td>
<td>0.75</td>
<td>Positive</td>
</tr>
<tr>
<td>Barren</td>
<td>None</td>
<td>0.14</td>
<td>None</td>
</tr>
<tr>
<td>Agriculture—crops</td>
<td>Negative</td>
<td>&lt; 0.001</td>
<td>Negative</td>
</tr>
<tr>
<td>Seasonally flooded habitats and wetlands</td>
<td>None</td>
<td>0.22</td>
<td>Negative</td>
</tr>
</tbody>
</table>

* Standardized classifications based on U.S. Geological Survey state Gap analysis projects.
† Association, based on ordinal logistic regression, classified as positive (P < 0.05), negative (P > 0.05), or none (P > 0.05).
‡ Based on 12 tularemia incidence classes: 0.001–0.049, 0.050–0.099, 0.100–0.199, 0.200–0.299, 0.300–0.399, 0.400–0.499, 0.500–0.749, 0.750–0.999, 1.000–1.499, 1.500–1.999, and 2.000–6.500 cases per 100,000 person-years.

Spatial risk models as public health tools
What are spatial risk models?

GIS-based statistical models predicting presence/absence, or a quantitative measure of the number of vectors or cases of disease for a particular geographical location displayed in map format.

Tick vector abundance, Mendocino Co., CA

Probability of human plague, Four Corners Region

West Nile incidence, Front Range, CO

Eisen et al. 2006
AJTMH 74: 632-640

Eisen et al. 2007
J Med Entomol 44: 530-537

Winters et al. 2008
AJTMH 78 654-665
Risk models as public health tools

- Targeting limited surveillance, prevention and control resources (Vector/Disease Control Programs)
  - Spatial targeting of:
    - vaccination, drug administration, or education campaigns
    - use of sentinel sites to monitor vector abundance
    - identifying areas for most effective use of pesticides

- Assessment of personal risk and need for personal protective measures (Physicians/Public)
  - Raising awareness of risk may lead to earlier accurate diagnosis and treatment
Requirements for spatial models used as public health tools

- High accuracy in predicting areas of elevated risk.
- Avoid over-estimating risk coverage.

Human plague cases by county
Source: CDC website

Human plague risk model
Source: Eisen et al. 2007 J Med Entomol 44: 530-537
Risk is typically presented at the county spatial scale in the U.S.

Reported Cases of Lyme Disease -- United States, 2006

Map from www.cdc.gov
County-scale reporting can misrepresent actual risk at the sub-county scale.

Fine-scale epidemiological data yield accurate fine-scale risk models

Human plague risk model

Human plague exposure sites 1957-2004

Eisen et al. 2007 J Med Entomol 44: 530-537
Benefits of epidemiological data

- A human case of a vector-borne disease unequivocally demonstrates human contact with the disease agent.
- Potential to identify socio-economic risk factors, in addition to environmental predictors.
**Drawbacks of epidemiological data**

- Some vector-borne diseases are not notifiable (e.g., babesiosis, Colorado tick fever, tick-borne relapsing fever)
- Case definitions and reporting practices can vary between states and over time
- There may be socio-economic differences in likelihood of seeking health care resulting in spatial disparities in disease detection
- Location of residence, rather than location of probable pathogen exposure, is often the only information available (e.g., Lyme disease, tularemia, West Nile virus disease)
- Cannot be used to assess risk on public lands where people do not reside, but where exposure could occur
- Disease severity may be related to mode of exposure (e.g., tularemia). If transmission differs across locations leading to spatial differences in disease severity (and reporting), use of epidemiological data could be problematic.
- Asymptomatic or mild infections may not be detected (e.g., West Nile virus disease)
Tularemia, and problems with epidemiological data

- Exposure site data not available
- Unless case files are re-examined, they likely include out-of-county exposures
- Removed from the list of notifiable diseases from 1994-1999
- Exposure can occur via arthropod bite, handling infected animals, ingestion of contaminated food or water
- Different *F. tularensis* sub-types differ in pathogenicity to humans and may differ in primary transmission routes

*Figure 4.* Counties with predicted risk of human exposure to tularemia in Arkansas-Missouri (gray). Counties reporting cases during 1990-2003 are displayed with hatched lines.

Eisen et al. 2008 AJTMH 78: 586-594
Spatial risk models based on arthropod vector data

Distribution maps have been used commonly in medical entomology, but typically maps depict presence/absence at a large spatial scale.

There is a need for fine-scale vector abundance maps because disease risk is often associated with the abundance of infected vectors.

Eisen and Lane, 2002, In Lyme borreliosis: Biology, Epidemiology and Control, CAB International, New York

Dennis et al. 1998 J Med Entomol 35, 629-38
**Benefits of vector data**

Many arthropod vectors transmit multiple human pathogens; therefore, modeling the distribution and abundance of a single vector can be used to assess potential for risk of exposure to multiple disease agents.

Rocky Mountain Wood Tick

Rocky Mountain Spotted Fever
Colorado Tick Fever
Tularemia

Distribution in Larimer Co., CO

Eisen et al. 2007 J Med Entomol 44: 694-704
**Benefits of vector data**

- Fine-scale assessments of vector abundance are readily attainable by field sampling.
- Vector abundance data are unequivocally linked to a specific spatial location.
- Vector modeling is independent of a human population base and thus can be used to assess risk on public lands.

Areas with high risk of exposure to *Ixodes pacificus* nymphs, CA

Eisen and Eisen 2008 J Med Entomol 45: 181-192
**Prevention for recreational vs. residential risk**

**Recreational**
- Avoid high-risk areas during peak vector activity periods
- Education campaigns to raise awareness of vector-borne diseases
- Daily tick checks
- Use of repellents

**Residential**
- Use of pesticides
- Landscape modification
- Removal of zoonotic hosts
- Education campaigns to raise awareness of vector-borne diseases
- Daily tick checks
- Use of repellents
**Drawbacks of Vector data**

- Collection of field data is expensive and time-consuming
- Abundance models are more informative than distribution models, both require knowledge of the distribution of the pathogen
- Human behavior affects the likelihood of a person becoming infected
- Some vector-borne diseases (e.g., plague, tularemia) can be transmitted by nonvector-borne routes
Modeling Lyme disease risk in California, combining epidemiological and vector data

Ixodes pacificus, the primary vector of B. burgdorferi to humans, is established in all but 3 CA counties.

Most Lyme disease cases occur in the northern part of the state.

Modeling of woodland habitats with growing degree-day values that fall within the range associated with high nymphal density within a single ecologically and climatically diverse CA county was useful for identifying LD risk areas at a fine spatial scale throughout the state.

Dennis et al. 1998 J Med Entomol 35, 629-38
Eisen et al. 2006 AJTMH 75: 669-676
Need for spatial risk models combining epidemiological and vector data: WNV disease in CO

Projected risk of exposure to Cx. tarsalis based on correlates with environmental factors

West Nile virus disease incidence per 100,000 person-years by census tract, 2002-2006

Risk index based on combined vector and human case data

**CONCLUSION**: The vector exposure risk model adds value to the epidemiologic risk map and vice versa.

Assess shared risk for diseases with similar prevention or control strategies

37% shared risk

Eisen et al. 2007 AJTMH 77: 999-1004
Summary

- Strive for high accuracy but avoid over-predicting risk areas
- Pros and cons for both epidemiological and vector data
- Go beyond vector distribution to modeling abundance
- Need for improved methodologies for collection and presentation of spatial epidemiological data
- Combine vector and epidemiological data provides a more complete assessment of risk than either alone
- Assess shared risk of diseases with similar prevention/control strategies
- Models are not end points, there should be a positive feedback between field data collection and model development
- Understand who the end-users will be and how they will use the models
Spatial modeling: From academic exercise to useful public health tool

- Improve accuracy and precision
  - Temporally-dynamic modeling
  - Integration of transmission efficiency and infection prevalence data for vector models

- Collection and reporting of vector and epidemiological data at appropriate spatial scales

- Positive feedback between field-collection/surveillance and modeling

- Assess end-user needs and modify model and data presentation accordingly

- Integration of Ecology, Epidemiology and Diagnostics
Modeling tick-borne disease risk in Missouri

- Which tick species and life stages serve as primary bridging vectors to humans?
- Where are humans at greatest risk of exposure to tularemia vectors?
- This information is critical for effectively targeting prevention and control activities.
Vector efficiency studies

- Developed a mouse model for infecting ticks with types *F. tularensis* types A1, A2, and B

- Evaluating relative transmission efficiency of *D. variabilis* nymphs for A1, A2 and B
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