Investigating the environmental factors associated with the expansion of Lyme disease in Maine, 2001-2014

COLUMBIA UNIVERSITY | MAILMAN SCHOOL of PUBLIC HEALTH
ENVIRONMENTAL HEALTH SCIENCES

Ecology, Evolution and Environmental Biology

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BACKGROUND

Lyme disease is the most prevalent vector-borne disease in North America and its incidence has increased dramatically in the United States since it was first described in Connecticut during the 1970's. Environmental factors known to influence the tick life cycle, including seasonal temperatures, precipitation, and deer abundance, have been associated with the distribution of the main vector, *Ixodes scapularis* and Lyme disease incidence (Diuk-Wasser et al. 2010, Levi et al., 2012). Understanding the biological and environmental drivers of tick distributions and Lyme disease transmission can inform predictive modeling and guide interventions to reduce human disease risk.

Study goal: Characterize the effects of environmental factors on Lyme disease expansion in Maine, where the incidence of Lyme disease and its geographic range has continually increased since electronic surveillance and laboratory reporting began in 2001 (Fig. 1). We hypothesize that environmental factors may be driving the expansion of the main vector, *Ixodes scapularis* or the Lyme disease agent, *Borrelia burgdorferi*.

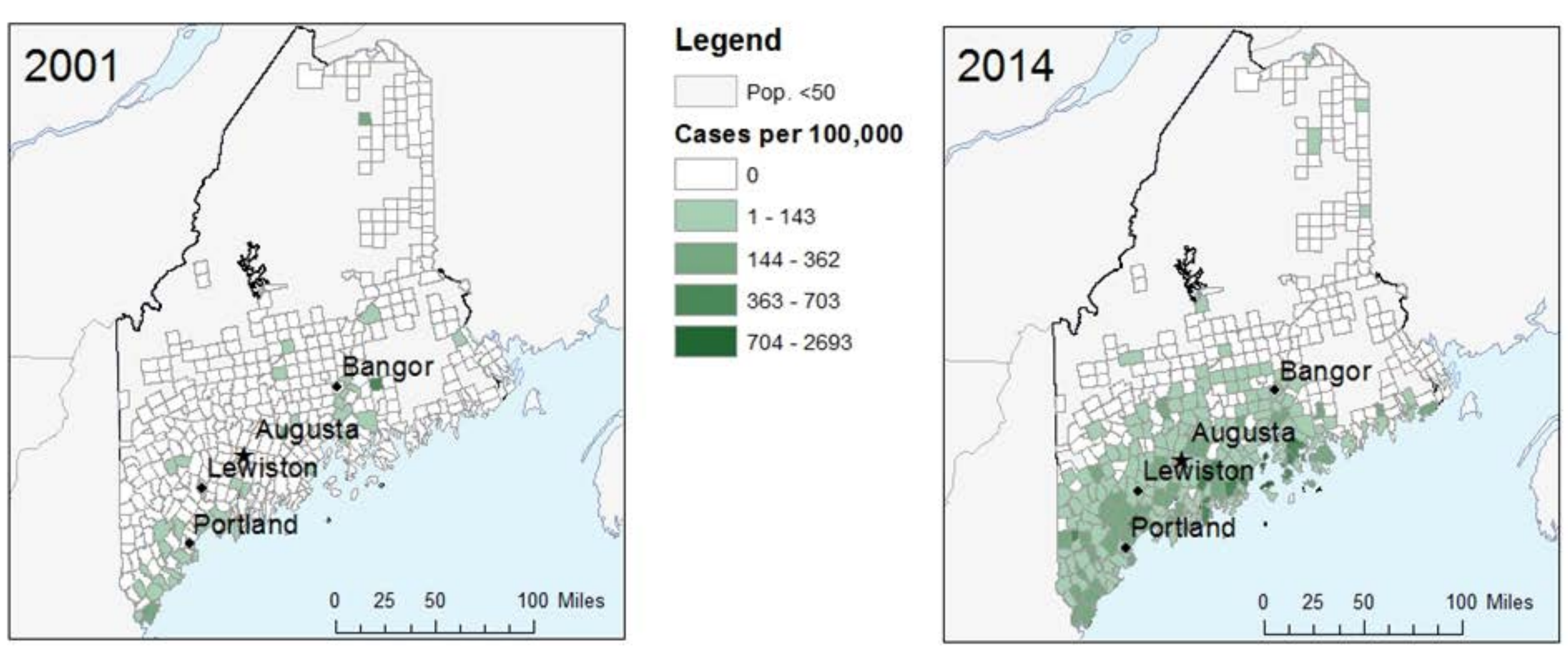
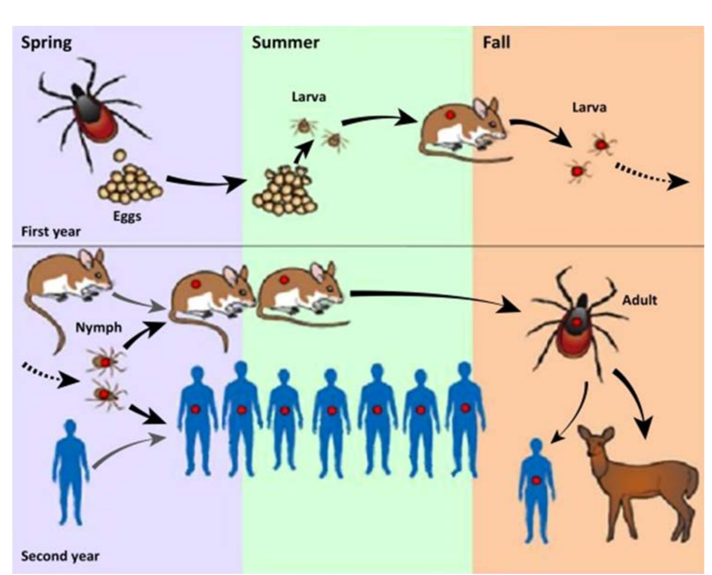


Figure 1. Distribution of Lyme disease incidence in 2001 and 2014. Initially, cases were reported almost exclusively along the southeastern seaboard. Today, Lyme disease has been reported in over a third of Maine towns, with new towns reporting cases every year.

Enzootic Cycle of *Borrelia burgdorferi* - Northeast and Upper Midwest USA

The life cycle of *Ixodes scapularis* includes three distinct life-stages: larva, nymph and adult. At each stage, the tick acquires a blood meal from a vertebrate host in order to mature to the next life stage. The *Borrelia burgdorferi* transmission cycle involves transmission from an infected small mammal or bird to a larvae, which then transmits it back to a mammal/bird in its subsequent blood meal as a nymph. Transmission to humans occurs through the bite of an infected tick.



METHODS

- Univariate and multivariate generalized linear regression, fitting logistic regression models were selected. The dependent variable was defined as whether or not a town had reported at least two cases of Lyme disease in any given year. The models accounted for repeated measures (towns) and included the log of town populations as an offset.
- Predictors associated ($p<0.1$) with a positive response in univariate models were incorporated into a full multivariate model. Backward manual selection was performed to obtain the final parsimonious model. GEE estimation, accounting for non-independence of observations, was used to derive the standard errors.

- **ENVIRONMENTAL DRIVERS:** Monthly climate data for Maine, collected from weather stations (N=107) across Maine between 2001-2014 (Fernandez et al. 2015), was downloaded from the National Centers for Environmental Information. Data was averaged for all weather stations within each county to generate the county-wide annual averages assigned to each town.

- **SURVEILLANCE BASED PREDICTORS:** Ticks found on people and pets were submitted to the Maine Medical Center Research Institute's tick identification program. Nymphal ticks are expected to be associated with same year risk (t), while adult ticks are expected to represent risk a year or more later (t-1) when the larvae molt to nymphs.

Variable	Description
Nymph count (t)	Same-year number of nymphal ticks submitted
Adult count (t-1)	Number of adult ticks submitted in the previous year
Annual air temperature (t)	Same-year annual air temperature (°F)
Annual precipitation (t)	Same-year annual precipitation (in. to hundreths)
Annual snow fall (t)	Same-year annual snow fall (in. to hundreths)
Deer harvest (t)	Average annual deer harvest by town
Report year	A binary variable representing change in case definition in 2008 (0 = Lyme disease never; 1 = Lyme disease ever)
Year	Year in which cases were reported

Table 1. Variables evaluated in univariate regression for inclusion in multivariate regression (if $p<0.1$).

RESULTS AND DISCUSSION

Multivariate Regression Analysis

Parameter	Estimate	Standard Error	95% Confidence Limits		Z	Pr>|Z|
Intercept	-668.36	35.720	-738.368	-598.350	-18.71	<.0001
Nymph Count (t)	0.38	0.082	0.223	0.543	4.70	<.0001
Adult count (t-1)	0.16	0.037	0.082	0.228	4.16	<.0001
Annual air temperature (t)	0.11	0.031	0.052	0.174	3.65	0.0003
Annual precipitation (t)	0.40	0.059	0.286	0.517	6.81	<.0001
Year	0.33	0.018	0.291	0.361	18.20	<.0001

Table 2. Multivariate analysis of environmental factors associated with the introduction and maintenance of Lyme disease in Maine towns (Generalized Estimating Equations, GEE).

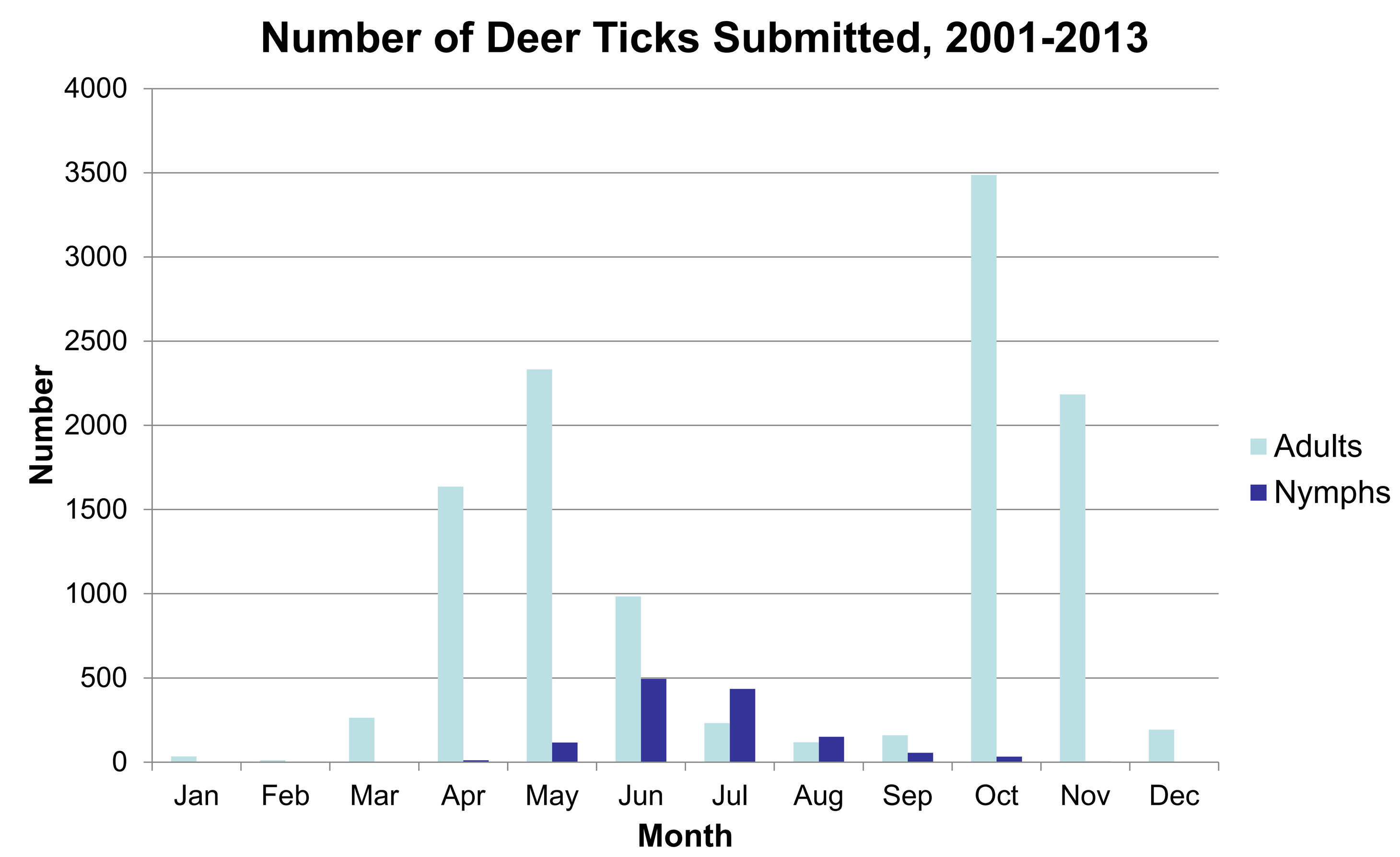


Figure 3. *I. scapularis* submissions by life stage and month of exposure.

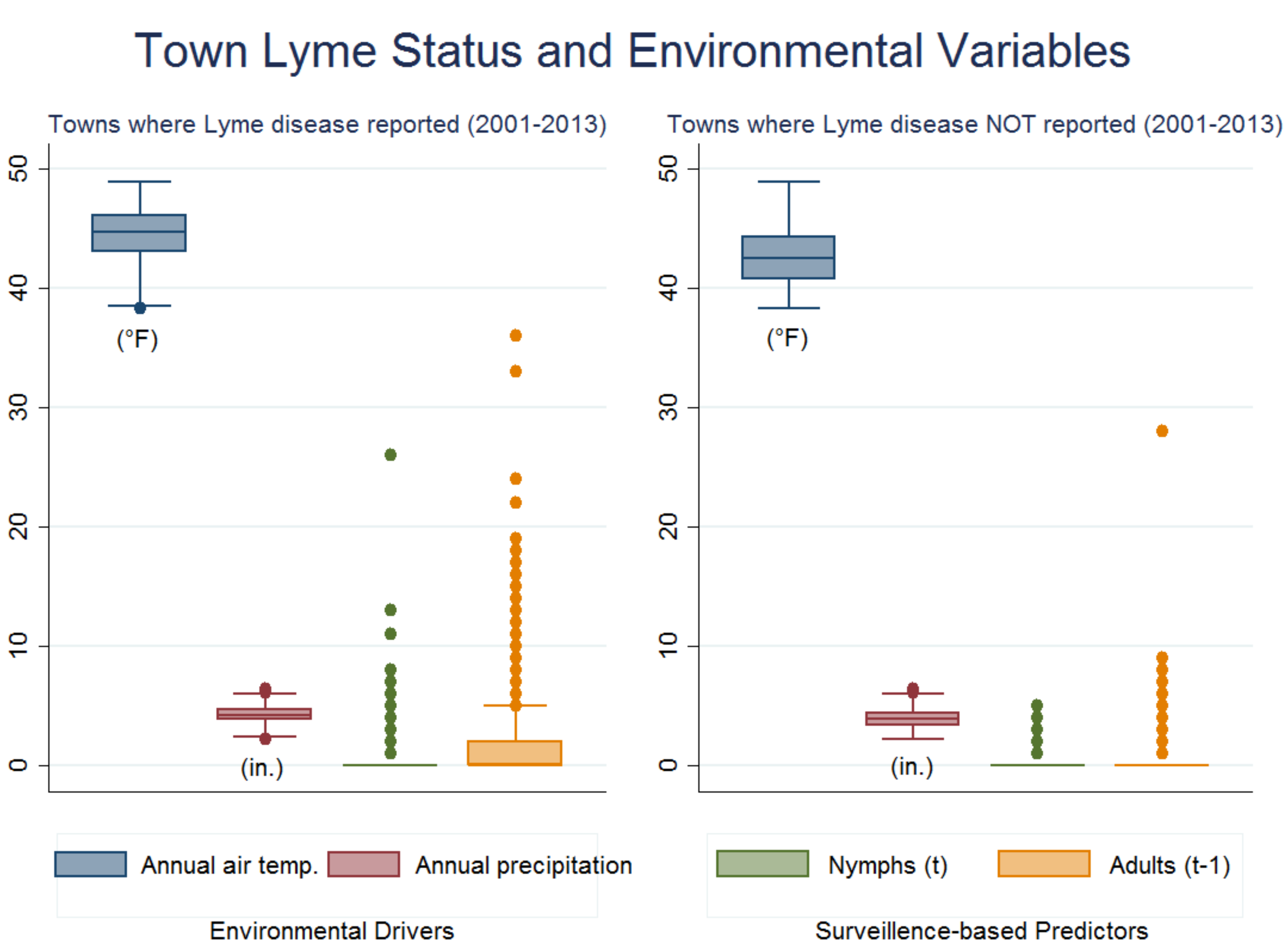


Figure 4. *I. scapularis* submissions by life stage and month of exposure.

CONCLUSIONS

- In Maine, the number of same-year nymphal deer tick submissions and the number of previous-year adult deer tick submissions were significantly associated with whether a town had or had not reported Lyme disease.
- County-level temperature and precipitation were significantly associated with whether a town had or had not reported Lyme disease.
- Tick surveillance data may be helpful in assessing risk of Lyme disease.

Next steps

- These preliminary analyses will inform additional spatiotemporal analysis of disease spread.
- Interactions between climate and temporal variables will be elucidated through finer level geographic resolution and additional lag.

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