# How Climate Affects the Tick Vector of Lyme Disease: A Critical and Systematic Review of the Literature


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## BACKGROUND

Lyme disease is the most common vector-borne disease in the United States and Canada, and the incidence rate is rising. Understanding the causes behind inter-annual fluctuations of Lyme disease incidence can help warn healthcare providers of upcoming outbreaks.

The primary vector for Lyme disease in the Eastern US and Canada is the blacklegged tick, *Ixodes scapularis*. Lyme disease in North America is caused by the transfer of the *Borrelia burgdorferi* pathogen from the tick to people during feeding. *I. scapularis* tick abundance is considered a good proxy for Lyme disease incidence, particularly the density of nymphs. Nymphs represent the middle life stage of the tick and they are the ticks that bite humans and potentially spread Lyme disease. Laboratory studies have shown that *I. scapularis* ticks are highly sensitive to the effects of temperature and relative humidity in ways that affect their survival, life cycle, behavior, and ability to transmit the *B. burgdorferi* pathogen.

The potential for contracting Lyme disease depends on three key factors: 1) the abundance of the tick vector (the density of host-seeking nymphs being particularly important), 2) the prevalence of *B. burgdorferi* infection in ticks, and 3) the contact frequency between infected ticks and humans. This systematic review is an attempt to examine the first factor, the abundance of the tick vector, by teasing out the important climate variables that affect *I. scapularis* tick abundance in North America and, by proxy, Lyme disease incidence.

## OBJECTIVES

The objective of this systematic review was to describe the way that climate variables are affecting Lyme disease incidence. This will be carried out by examining the effects of climate variables on *Ixodes scapularis* tick abundance.

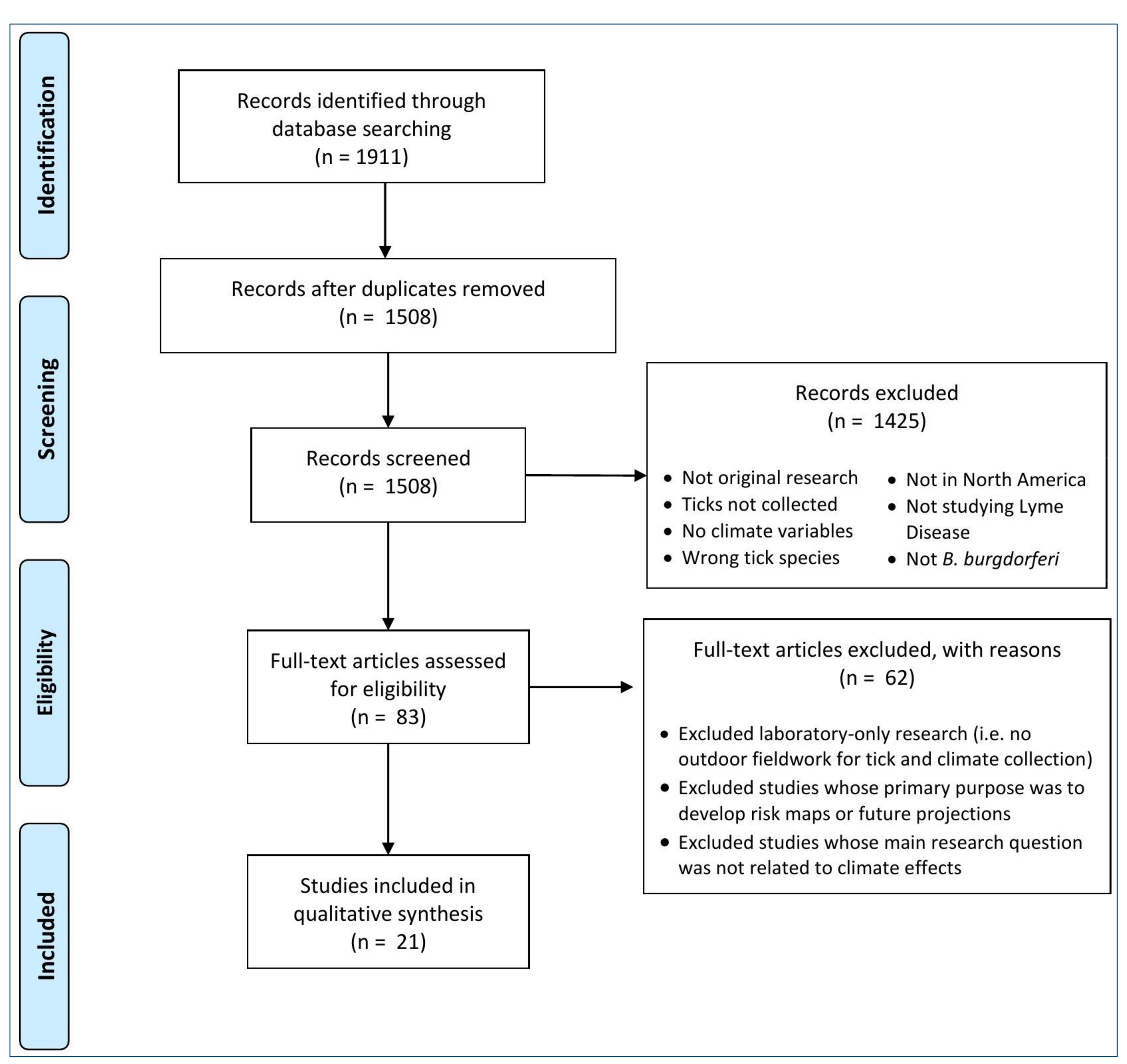
## METHODS

A systematic review was conducted using the Navigation Guide, a methodology developed to review environmental public health literature and note the risk of bias, the quality of the evidence, and the strength of the evidence of an exposure-outcome relationship.

A literature search was conducted on October 4, 2017 and found 1911 articles using the electronic databases Scopus, ProQuest, Pubmed, and Web of Science.

In the final analysis, 21 articles were included.

**Figure 1. Systematic Review PRISMA Flow Diagram**




## RESULTS

**Table 1. Description of Studies Included in Review**

| Authors | Type of Study | Location | Tick Collection Method | Ticks Collected | Tick Life Stage | Established Populations? | Climate Collection Method |
|---|---|---|---|---|---|---|---|
| **Amerasinghe et al. 1993** | Ecological | Maryland, US | Hunter-killed White-tailed deer | 3,434 | Adult | Established | County-level Weather Stations |
| **Berger et al. 2014a** | Retrospective, Ecological, Time Series | Rhode Island, US | Drag-sampled | 1,608 | Nymphs | Established | Data Logger + Weather Stations |
| **Berger et al. 2014b** | Ecological | Rhode Island, US | Flagged | 1,474 | Nymphs | Established | Data Loggers |
| **Brunner, Killilea, & Ostfeld 2012** | Prospective, Quasi-Experimental, Ecological | New York State, US | Unspecified | 1,100 | Nymphs | Established | Data Loggers |
| **Burtis et al. 2016** | Retrospective, Ecological, Time Series | New York State, US | 1) Drag-sampled, 2) White-footed mice and Eastern chipmunks | Unspecified | Larvae, Nymphs | Established | County-level Weather Stations |
| **Clow, et al. 2017** | Ecological | Ontario, Canada | Drag-sampled | Unspecified | Larvae, Nymphs, Adults | Newly established | County-level Weather Stations |
| **Gabriele-Rivet et al. 2015** | Ecological | New Brunswick, Canada | Drag-sampled | 5 | Larvae, Adults | Not established | Satellite |
| **Gatewood et al. 2009** | Ecological, Time Series | Northeastern and Midwestern US | Drag-sampled | 35,846 | Larvae, Nymphs | Various levels | County-level Weather Stations |
| **Goltz & Goddard 2013** | Ecological | Northern Mississippi, US | Drag-sampled | 262 | Adults | Established | Unspecified |
| **Hayes, Scott & Stafford 2015** | Retrospective, Time Series, Ecological | Connecticut, US | Drag-sampled | 6,165 nymphs/ha | Nymphs | Established | Nearest Weather Station |
| **Jones & Kitron 2000** | Ecological, Time Series | Northern Illinois, US | 1) White-footed mice, 2) Drag-sampled | Unspecified | Larvae, Nymphs | Established | Nearest Weather Station |
| **Khatchikian et al. 2012** | Ecological, Time Series | New York State, US | Drag-sampled | 19,602 | Nymphs, Adults | Established | Satellite |
| **Leighton et al. 2012** | Retrospective, Ecological | Canada (nationwide) | Humans and domestic animals | Unspecified | Larvae, Nymphs, Adults | Newly established | County-level Weather Stations |
| **Levi et al. 2015** | Retrospective, Ecological, Time Series | New York State, US | White-footed mice and Eastern chipmunks | 447,638 | Larvae, Nymphs | Established | Nearest Weather Station |
| **Oliver & Howard 1998** | Ecological | Appalachian Trail, US | Drag-sampled | 46 | Larvae, Nymphs, Adults | Various levels | Data Loggers |
| **Ostfeld et al. 2006** | Retrospective, Ecological, Time Series | New York State, US | Drag-sampled | 3.59-21.07 ticks per 100m$^2$ | Larvae, Nymphs | Established | Nearest Weather Station |
| **Ostfeld et al. 2001** | Ecological, Time Series | New York State, US | Drag-sampled | Unspecified | Nymphs | Established | Nearest Weather Station |
| **Schulze & Jordan 2005** | Ecological | New Jersey, US | 1) Drag-sampled, 2) Walking surveys | Unspecified | Larvae, Nymphs, Adults | Established | Data Loggers |
| **Schulze et al. 2009** | Ecological, Time Series | New Jersey, US | Drag-sampled | 3,416 | Nymphs | Established | Nearest Weather Station |
| **Vail & Smith et al. 1998** | Ecological | New Jersey, US | Drag-sampled | 2 to 10 ticks per 100m$^2$ | Nymphs | Established | Data Loggers |
| **Werden et al. 2014** | Ecological, Natural Experiment | Ontario, Canada | Drag-sampled | 1,354 | Nymphs | Various levels | Data Loggers |

Three analyses were conducted with tick abundance, a proxy for Lyme disease incidence: 1) climatic moisture, 2) temperature, 3) temperature + moisture. Risk of bias was generally rated "low" or "probably low" and quality of evidence was rated "moderate" for all studies.

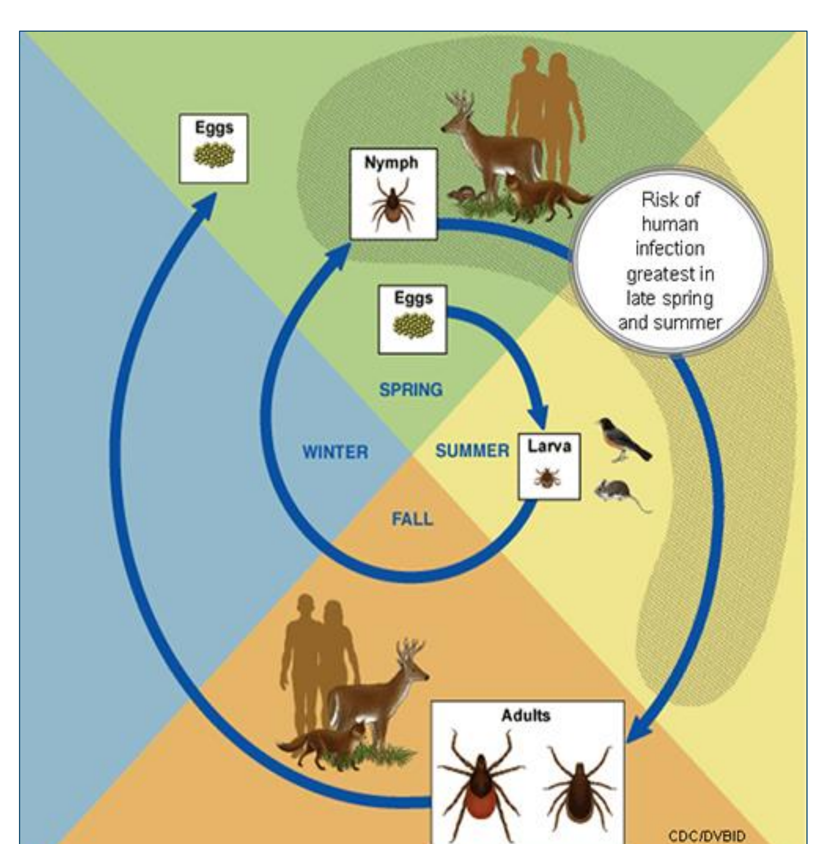
**A positive, moderate-strong relationship was observed between climatic moisture and tick abundance** (r=0.82; $r^2$=0.56 to 0.64) in 56% of studies. The relationship was observed in 60% of nymph abundance studies and in 71% of studies with a few months time lag between climatic moisture and tick abundance. The relationship with climatic moisture was rated as having "sufficient" strength of evidence, indicating that a relationship exists but more research is needed.

While relationships were observed between tick abundance and temperature (70% of studies, r=(-0.89) to 0.93; $r^2$=(-0.56) to 0.34) and temperature + moisture (38% of studies, $r^2$=0.50), direction and magnitude could not be determined. The strength of evidence was rated as "inadequate" for both analyses (data not shown).

**Table 2: Tick Abundance and Climatic Moisture**

| AUTHORS | TICK VARIABLE | CLIMATE VARIABLE | CLIMATE CONCURRENT TO TICK VARIABLE? | STATISTICAL METHOD | DIRECTION OF RESULTS | STRENGTH OF RESULTS |
|---|---|---|---|---|---|---|
| AMERASINGHE ET AL. 1993 | Tick Abundance (Adults) | Prec | 0-12 months prior (annual measurement) | Stepwise multiple linear regression | Positive** | $r^2$=0.56 |
| BERGER ET AL. 2014A | Tick Abundance (Nymphs) | Desiccation | 2 years prior | Linear regression | Negative* | - |
| BERGER ET AL. 2014B | Tick Abundance (Nymphs) | RH | 8-14 days prior | Applying AIC to negative binomial regression models | Positive* | - |
| GABRIELE-RIVET ET AL. 2015 | Tick Abundance (All Life Stages) | Prec | 0-30 years prior (30 year annual average) | Applying AIC to logistical regression models | - | - |
| GOLTZ & GODDARD 2013 | Tick Abundance (Larvae and Adults) | Prec | 0-12 months prior (annual measurement) | Univariate analyses | - | - |
| HAYES, SCOTT & STAFFORD 2015 | Tick Abundance (Adults) | Vapor Pressure Deficit | Concurrent | ANOVA | - | - |
| JONES & KITRON 2000 | Tick Abundance (Nymphs) | Winter Prec | 6-8 months prior (January) | Spearman Rank Correlation | Positive* | $r^2$=0.64 |
| OLIVER & HOWARD 1998 | Tick Abundance (Larvae) | Prec | 12 months prior | Spearman Rank Correlation | Positive* | r=0.82 |
| VAIL & SMITH ET AL. 1998 | Tick Abundance (All Life Stages) | RH | Concurrent | Student's t-test | - | - |

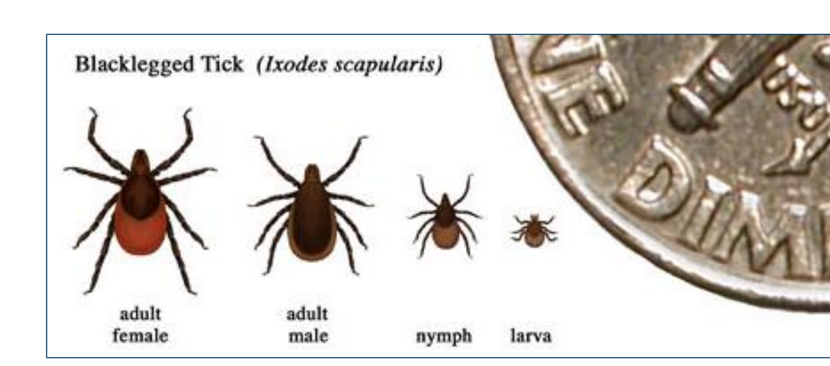
* significance at $p < 0.05$ or lowest AIC score, ** significance at $p < 0.01$. Abbreviations: prec, precipitation; RH, relative humidity; AIC, Akaike information criterion; ANOVA, analysis of variance




## CONCLUSIONS

As climatic moisture increases (especially when measured yearly or 0.5–2 years prior), tick abundance (and, by proxy, Lyme disease incidence) increases. However, more evidence is needed to confirm this relationship. Nymph abundance studies, a more accurate proxy, was more likely to show this relationship.

Climate change is predicted to increase precipitation in Northeast US/Canada, which will likely increase tick abundance and therefore the rate of Lyme disease incidence. Understanding the ways that moisture-related variables, like precipitation, relative humidity, vapor pressure deficits and desiccation events, are affecting the *I. scapularis* tick population will prove vital for predicting Lyme disease incidence and aiding prevention efforts in the future.




Left and Right Pictures from CDC: https://www.cdc.gov/lyme/transmission/blacklegged.html

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