Climate Change in New England: The Implications for a Vector-Borne Disease

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ABSTRACT

Recent studies indicate that changing climate trends in New England will increase the possibility of the introduction of new infectious disease vectors or trigger an increase in current vector populations. Local vector-borne diseases, primarily Lyme disease, *Borrelia burgdorferi*, could become a more serious health problem if conditions become more favorable for transmission of the spirochete. Previous research has shown that the population size of the deer tick, Lyme disease vector *(Ixodes scapularis)*, is sensitive to the likely shifts in temperature and precipitation. If these variables change in the Northeast region where Lyme *borreliosis* is endemic, we can expect the tick population to also change and predict changes in disease frequency and distributions. I examined fifty-four years of monthly temperature and precipitation data collected at sixteen stations from southern New England to the Canadian border. I found significant changes in mean temperature, mean minimum temperature, and total precipitation ($P < 0.05$). A 0.8º C increase in the average winter temperature and a 0.4º C increase in the average summer temperature were observed in a fifty-year interval. Increasing temperatures and summer rains, and decreasing winter precipitation, as found in this study, could promote a major rise in the *Ixodes* population thereby prompting a jump in Lyme disease incidence among the human population.

INTRODUCTION

If global temperatures continue to rise, it is very likely that disease vectors will migrate to new areas which have suitable climatic conditions for survival. Patz, et al. (1996) refer to emerging and reemerging infectious diseases as those “increasing in incidence in the recent past or threatening to increase in the near future.” Climate change could increase prevalence of disease in places where they already exist; or, the new climate could lead to the elimination of vector and disease altogether in that area. An understanding of the factors that affect the success or failure of disease vectors, e.g. ticks or mosquitoes, allows outbreaks or declines in both vectors and disease incidence to be predicted. Some climate-based models for malaria and dengue fever presume moisture and temperature will significantly impact vector biology and the ability to sustain transmission (Craig et al. 1999; Lindsay and Birley 1996; Hales et al. 2002; Githeko and Ndegwa 2001). The prevalence of infectious diseases are subject to the influence of environmental, biological and social variables, yet without an effective vector, many diseases cannot transmit, reproduce, or survive.

Climate change will inevitably lead to shifts in the spatial distribution of diseases, their health effects and the scale of impact. The Intergovernmental Panel on Climate Change estimates that the global mean surface temperature rose 0.6±2° C over the past 100 years (Intergovernmental Panel on Climate Change 2001). Continental precipitation also has increased between 5-10% during the past 100 years. The 20th Century was the warmest in the millennium and there is no indication that this global trend will diminish; in fact, there is evidence that it will accelerate.

In the northeastern United States, the long, cold winters have historically prevented the occurrence of warm-weather mosquitoes and other common disease vectors. However, climate change is affecting the region, which has and will leads to significant transformations in the distribution of both flora and fauna. The current estimates of about 0.39º C warming in New England over the past 100 years and a 4% rise in annual precipitation are on par with the global averages, though existing data suggest there was a lot of variation across the region (New England Regional Assessment Group 2001).

Warmer winters and wetter summers represent longer breeding seasons and more feeding days for many disease vectors; thus, an increase in disease transmission could be expected. The incidence of Lyme disease (*Borrelia burgdorferi*), the most important vector-borne disease in the northeastern U.S., is dependent on climatic variables, such as mean temperature, precipitation, season length and variation (Centers for Disease Control Division of Vector-Borne Infectious Diseases 2001a).

Lyme Disease

The increasing number of Lyme disease cases reported nationally to the Centers for Disease Control (CDC) may be an indication of the influence of a changing climate. In 1990, there were 7,943 cases as compared to 17,730, in 2000, making it the most common vector-borne disease in the United States (Centers for Disease Control 2001b, 2002; Steere 2001). Three factors are essential for the occurrence of Lyme: the existence and survival of Lyme disease bacteria *B. burgdorferi,* a tick-borne spirochete*; Ixodes* ticks to transmit the bacteria; and the presence of mammals such as white-footed mice (*Peromyscus leucopus*) and white-tailed deer (*Odocoileus virginianus*) to provide the blood meal sustaining the ticks (Centers for Disease Control Division of Vector-Borne Infectious Diseases 2001a).

The primary foci of Lyme disease endemicity in the U.S. are in the Northeast (Maine to Maryland), the Midwest (Wisconsin and Minnesota), and the West (northern California and Oregon) (Steere 2001). The states with the highest incidence are Connecticut, Rhode Island, New York, Pennsylvania, Delaware, New Jersey, Maryland, and Massachusetts (Centers for Disease Control 2001b). Both the biological and clinical manifestations of Lyme disease are well understood. The sequencing of the entire genome of the spirochete, development of animal models for pathogenesis studies, establishment of diagnosis and treatment guidelines, and creation of a prophylactic vaccine have all come about within the past twelve years (Steere 2001).

Lyme disease is rarely, if ever, fatal, but the morbidity associated with it can be very severe and debilitating. The incubation period between infection to erythema migrans is usually between 7-14 days, though it may be as short as three days or as long as thirty. Once the spirochetes enter the body, they will be distributed away from the bite area via cutaneous, blood-borne and lymphatic pathways. Some people remain asymptomatic and their infection is determined by serological testing, whereas others contract flu-like symptoms. Lyme disease is difficult to diagnose because of the vague symptoms and varying degrees of severity (Centers for Disease Control Division of Vector-Borne Infectious Diseases 2001b).

Lifecycle of *Ixodes* Ticks & the Ecology of Lyme Disease

Black-legged ticks (*Ixodes*) are responsible for disease transmission and exposure pathways for Lyme disease around the world. *Ixodes scapularis* is responsible for transmitting the *B. burgdorferi* bacteria to humans in the northeastern and north-central United States (Centers for Disease Control Division of Vector-Borne Infectious Diseases 2001a). The two-year lifecycle of *Ixodes* include: adult females laying eggs on the ground in early spring; eggs hatching into larvae during the summer; the larvae securing a blood meal from mice or other small mammals, deer or birds from late summer into early fall; the larvae molting into nymphs and laying dormant from early to middle fall until the following spring; the nymphs reemerging and feeding on rodents, other mammals, birds and humans in the late spring and summer of their second year; nymphs molting into adults in the fall and feeding mainly on large mammals (deer) and humans; finally, the adult females dropping off of the large mammals to lay their eggs in the spring.

Ticks, rodents, and other non-human vertebrate animals serve as a reservoir for *B. burgdorferi*. The bacteria are able to grow and mature within these hosts without killing the carriers. Larvae and nymph ticks are infected with the Lyme disease spirochete the first summer after they hatch because they feed on mice and other mammals already infected. The nymphs can then transmit *B. burgdorferi* while feeding on other small mammals and humans.

The autecology of the ticks determines who is likely to get sick and where. *Ixodes* prefer temperate regions with a humid microclimate at ground level. In the eastern US, *I. scapularis* are found in deciduous forests with plenty of leaf litter. The leaf litter provides a moist protective barrier from snow, rain and wind. *I. scapularis* jump on to host animals that brush against tips of grasses, shrubs and leaves. Therefore, people who spend a lot of time working and playing outdoors or who live in wooded areas are the most susceptible to tick bites.

Climatic Factors

The survival of *Ixodes* ticks is heavily impacted by weather variables. While there is little experimental evidence of the tick response to changing climate conditions in the New England region, studies in other areas can provide a template for what we may be able to expect. For instance, major summer droughts decreases larval *I. scapularis* abundance the years immediately following (Jones and Kitron 2000). Less precipitation leads to reduced vegetation and increased rates of *Ixodes* desiccation, as the ticks have limited ability to control water loss. Once nymphs, and especially larvae, are dehydrated, reviving them is much more difficult than for dehydrated adults (Yoder and Spielman 1992). Heightened sensitivity to humidity is explained by the non-engorged ticks' ability to absorb atmospheric water directly through their cuticle. Slightly drier and hotter temperatures reduce questing of nymph ticks for blood meals and larger mammals (Randolph and Storey 1999). When water stressed, the nymphs will move lower in the vegetation to find cooler, wetter conditions. They usually reach the environmental conditions they prefer before questing for, or feeding on, the smaller rodents close to the ground. This suggests immature ticks grow quiescent to escape desiccation. Previous research has found a positive correlation between summer moisture and Lyme disease in several northeastern states (Subak 2003).

Temperatures can also impact tick populations for the next 1-2 years. The ideal incubation temperature for *I. scapularis* larvae is about 24ºC (Lindsay et al. 1995). Threshold temperatures for egg deposition by females and larval emergence from egg stage are approximately 6º C and 11º C, respectively. The tick development rate is thus temperature dependent (Harris 1959). As summer and winter seasons are critically important for the tick life cycle, and Ixodes are particularly sensitive to departures from norms during these months. Summer months are important because nymphs emerging from the dormant larvae stage as well as adults feed the most during June and July, which explains why two-thirds of Lyme infections occur during the summer months (Subak 2003). Because the month of December usually marks the end of the annual activity cycle for *I. scapularis*, warmer average temperatures, above 5° C, can extend the adult breeding season and increase breeding success (McEnroe 1977). Winters with particularly cold temperatures can decrease *I. scapularis* populations, resulting in lower infections rates the following year. Rises in minimum nighttime and winter temperature, 1º C across the region, may also contribute to the spreading of Lyme disease within and beyond New England (New England Regional Assessment Group 2001).

The relationship between the disease vector, *Ixodes* ticks, and environmental and climatic variables is complex. Small climatic shifts could result in a decreased or increased population of ticks or a decline or upsurge in Lyme incidence. In this paper, I seek to examine how changes in precipitation or temperature over the past 50 years may have impacted black-legged tick populations and the incidence of Lyme disease across New England. I also compare regional temperature and precipitation data reported by the Northeast Regional Climate Center (2002) with trends reported in the New England Regional Assessment Report (New England Regional Assessment Group 2001). Variations in tick prevalence and disease incidence between coastal and inland areas led me to look at a latitudinal transect from the southern tip of Rhode Island northward to the Canadian border. The latitudinal study identifies whether a climate trend occurs uniformly across the region or more strongly in a particular area. Weather variables were investigated to see if a noticeable change has occurred along the transect and then what impact this might have had on the Lyme disease vector and, ultimately, transmission of infection.

METHODS

Mean temperature, mean minimum temperature and mean maximum temperature, all monthly averages of daily temperatures, and precipitation or, “liquid equivalent,” were the variables examined. The data was delineated by month, and available for fifty or more years. Fifteen criteria weather stations were chosen from Rhode Island, Massachusetts and New Hampshire to characterize variations roughly within a transect running north from Rhode Island along the eastern and western boundaries of the state.

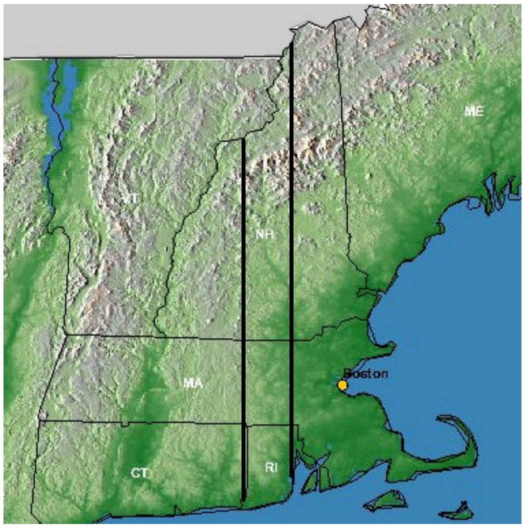


Figure 2. Vertical transect of land along which climate stations are located (National Geographic 2002)

Station	Latitude	Longitude	Elevation (m)
Block Island, RI	41º 10’ N	71º 35’ W	34
Kingston, RI	41º 29’ N	71º 32’ W	30
Newport Rose, RI	41º 30’ N	71º 21’ W	5
Providence T.F. Green State Airport, RI	41º 43’ N	71º 26’ W	16
West Medway, MA	42º 8’ N	71º 26’ W	64
East Milton Blue Hill Observatory, MA	42º 13’ N	71º 7’ W	192
Worcester Regional Airport, MA	42º 16’ N	71º 53’ W	301
Bedford, MA	42º 29’ N	71º 17’ W	49
Nashua, NH	42º 47’ N	71º 29’ W	40
Keene, NH	42º 57’ N	73º 19’ W	155
Durham, NH	43º 9’ N	70º 57’ W	24
Concord Air, NH	43º 12’ N	71º 30’ W	105
Plymouth, NH	43º 47’ N	71º 39’ W	201
Mt. Washington, NH	44º 16’ N	71º 18’ W	1909
Berlin, NH	44º 27’ N	71º 11’ W	284
1st Connecticut Lake, NH	45º 5’ N	71º 17’ W	506

Table 1. Climate stations and location

Datasets obtained from the NRCC, through the Climod data share program, were grouped my month and year. Data from winter (December, January, February) and summer (June, July, August) months were analyzed. Any month with more than five missing days was excluded to minimize error. Because a great deal of temperature fluctuation can occur in a decade time span, any weather station missing 10 consecutive years between 1948-2002 was excluded. All data stations were still in operation and had continuous data that went back to 1948 or earlier; however, the minimum record length was 45 years, (Bedford, MA, West Medway, MA, Newport Rose, RI, and Plymouth, NH).

All stations in Massachusetts, Rhode Island, and New Hampshire with long-term records, meaning they started collecting data in 1926 or earlier and had a continuous record until the present, were also examined. Only eight stations were available for the longer-term data analysis, only two of which were not in the transect data sites, Boston-Logan Airport, MA and Lawrence, MA. It appeared that climate stations near airports held consistently higher baseline temperatures due to urban effects, though they also were increasing with climate change.

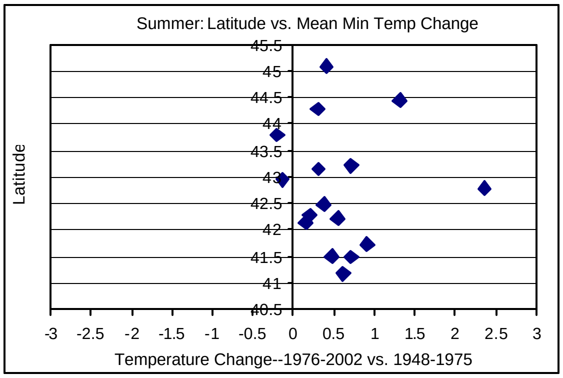
First, a comparison between mean weather characteristics in 1948-1975 and 1976-2002 was conducted to determine whether there was a difference between the two time periods; second, both the 1948-2002 and the long-term records were analyzed for an overall trend and rate of change using a linear regression model. Using JMPIn (SAS Institute 1989-2000), precipitation and mean, mean minimum, and mean maximum temperature variables were tested by station to compare winter and summer months. A paired *t*-test determined whether warming or cooling occurred from the first time period to the second. Another paired *t*-test compared the difference between the means of 1948-1975 and 1976-2000, to test for significant change from zero; positive change indicated warming. Scatterplots were also generated to identify the latitude of stations with temperature and precipitation changes differing from zero.

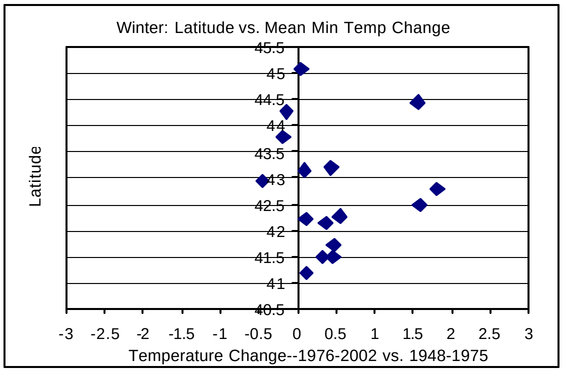
Linear regression analysis was used for all sites, from 1948-2002, to find the rates of change for both precipitation and temperature data. The long-term data was also used to find the rates of change of climate variables across stations, from 1921-2002. Comparing the significance of the slopes from zero followed, with a *t*-test. The short-term and long-term datasets were analyzed alike.

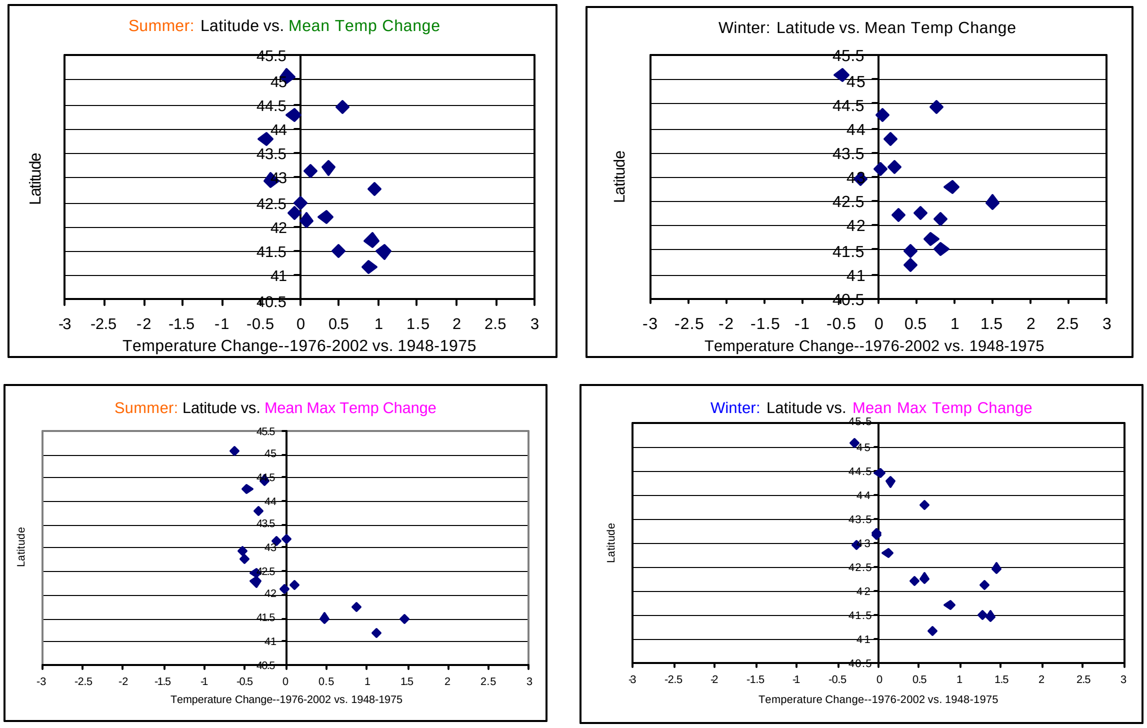
RESULTS

Temperature

From 1948-2002 both winter and summer temperatures increased. Comparing mean temperature change for the periods 1948-1975 and 1976-2002 show no significant change in 14 of 16 stations. Yet, when the aggregate differences between monthly means of the two time periods are taken by season, the trend indicates a statistically significant ($P < 0.05$) increase for mean temperature, summer, and mean minimum temperature, summer and winter (Table 3). The decrease in mean winter temperature is attributed to a decrease in January temperatures, for all temperature variables, that offsets general increases in December and February temperatures. Winter mean maximum temperature increased regionally 0.3°C in 54 years, significant at $P < 0.005$, whereas summer maximum temperatures showed no significant regional trend; Rhode Island clearly increased summer maximum temperatures whereas Massachusetts and New Hampshire decreased. Mean minimum temperature increased consistently for all three states in 54 years, averaging 0.24° C for both winter and summer months. Figure 3 identifies a relationship between latitude and temperature increase, drawing on the difference between means of time periods; southern sites showed a greater temperature increase.






Summer: Latitude vs. Mean Temp Change

Winter: Latitude vs. Mean Temp Change

Summer: Latitude vs. Mean Max Temp Change

Winter: Latitude vs. Mean Max Temp Change

Figure 3. Difference between the means of the two time periods; i.e., a difference greater than zero means 1976-2002 was warmer than 1948-1975.

Linear regression, following monthly averages from 1948 to 2002, shows a positive trend for mean temperature in 80% of Massachusetts station/months, 60% of New Hampshire station/months, and 97% of Rhode Island station/months. The long-term data (1926 or earlier) demonstrated increases in winter and summer months for all eight stations, except for January where a decrease is occurring (see Fig. 4).

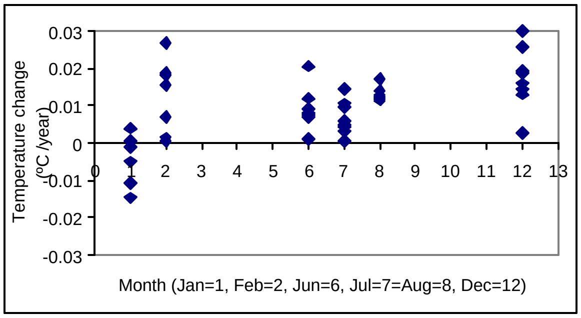
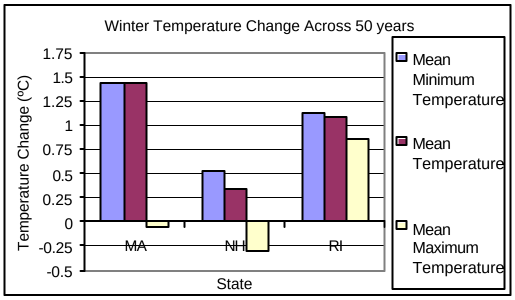


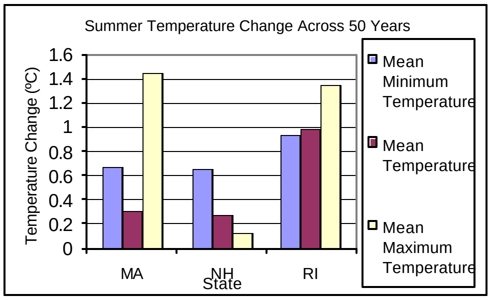
Figure 4. Mean temperature, long-term data (1926 or before) as rate of ºC change per year. Climate sites include Boston-Logan Airport, MA; East Milton Blue Hill Observatory, MA; Lawrence, MA; Berlin, NH; Concord Municipal Airport, NH; Durham, NH; Keene, NH; Kingston, RI.

The slope aggregates per station per season (winter/summer) differing from zero proved to have highly significant results for $P < 0.05$ (Table 3-b). Temperature again showed significant increases indicating a rise in daily mean and minimum temperatures during both summer and winter months, and winter mean maximum temperatures. By state, Massachusetts had the largest winter increase at approximately 1.4º C over fifty years. Rhode Island was close behind at 1.1º C increase, but had the greatest summer increase of 0.9º C mean minimum to 1.4º C mean maximum temperatures.

	WINTER			SUMMER		
State	Mean Min	Mean	Mean Max	Mean Min	Mean	Mean Max
Massachusetts	1.45	1.44	-0.05	0.67	0.31	1.45
New Hampshire	0.54	0.34	-0.3	0.65	0.27	0.13
Rhode Island	1.12	1.08	0.87	0.93	0.98	1.35

Table 2. Fifty-year seasonal temperature (ºC) increase or decrease by state.





Precipitation

Total precipitation for winter and summer months followed expected climate change hypotheses: Data showed a decrease in winter precipitation and an increase in summer precipitation. As with temperature data, the paired t-tests between 1948-1975 and 1976-2002 were consistent with trends but were not statistically significant.

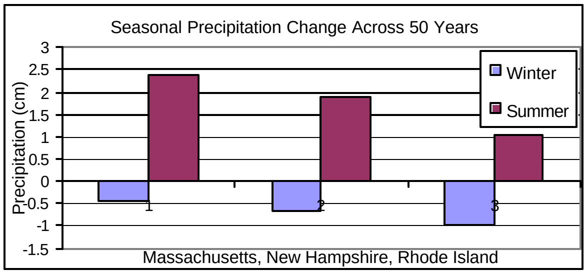


Figure 5. Fifty-year seasonal precipitation (cm) increase or decrease by state.

However, when aggregated by season and when the differences between the means were tested, both winter and summer months proved to have strong statistical significance. The precipitation data for the entire fifty-four year study period provided evidence for wetter summers and drier winters. A summer rainfall increase of 0.01 cm/yr and a difference of 0.46 cm more precipitation in the second time period were both highly significant to P < 0.0001. Also, winter decreases of 0.03 cm/yr and a 0.432 cm drop between time periods further supported findings.

	a) Difference between time period means	Standard error	P-value	T-statistic	b) Mean slope	Standard error	P-value
Mean Temperature	(ºC)				(ºC/yr)		
Winter	-0.358	0.283	0.225	-1.265	0.016	0.004	0.002
Summer	0.161	0.067	0.03	2.4	0.008	0.002	0.005
Mean Min. Temperature							
Winter	0.249	0.091	0.016	2.729	0.018	0.005	0.001
Summer	0.241	0.186	0.041	2.223	0.014	0.003	0.0004
Mean Max. Temperature							
Winter	0.282	0.083	0.004	3.411	0.015	0.005	0.006
Summer	0.017	0.088	0.853	0.188	0.001	0.003	0.683
Total Precipitation	(cm)				(cm/yr)		
Winter	-0.432	0.031	0.001	-3.941	-0.03	0.001	0.053
Summer	0.455	0.065	<0.0001	6.983	0.014	0.003	<0.0001

TABLE 3. Evidence of overall temperature (ºC) increase across time periods and precipitation (cm.) decrease in winter (Dec, Jan, Feb) and increase in summer (Jun, Jul, Aug). a) Positive difference comparison between means of time periods 1948-1975 and 1976-2002. b) Average rate of change (ºC/yr) from 1948-2002.

DISCUSSION

With the warming trend, female ticks may have more opportunities to lay eggs; larvae may emerge sooner from the eggs; the feeding season in the late summer and early fall may lengthen; the breeding season may continue later into the fall; and the wetter summers may avert desiccation. Regional climate change in New England is therefore creating an even more suitable environment for ticks, which will likely cause an increase in the population rather than a decrease.

Black-legged ticks, as with many organisms, are highly susceptible to fluctuations in temperature and humidity. Currently, the average annual temperature ranges from 10º C in southern New England to around 4º C in the northern states (New England Regional Assessment Group 2001). The average annual precipitation in the region is approximately 102 cm per year. If the temperature change reaches even a 1º C rise over the next few years, data indicates that certain regions will begin to see earlier egg-laying and longer breeding seasons. Average summer precipitation has increased 2 cm in the past fifty years, which will enable ticks to quest higher in the vegetation and reach larger host animals without the threat of desiccation. Presumably, this would lead to more ticks on humans and a greater risk of infection transmission.

With the appropriate conditions over a several year time span, a tick upsurge could therefore manifest in higher transmission and incidence rates of Lyme disease. The CDC (2002) reported rising numbers of Lyme *borreliosis* cases during the 1990's, the warmest decade of the 20th century. In 2000, New England closely trailed the Mid-Atlantic States in number of Lyme disease cases, with 3,773 cases in Connecticut, 1,158 in Massachusetts and 675 in Rhode Island. Maine, New Hampshire and Vermont had fewer than 100 cases. The temperature data indicated that New Hampshire showed the least amount of change, but Massachusetts and Rhode Island are clearly warming more significantly. Both *I. scapularis* and *B. burgdorferi* are making their way up the Eastern seaboard and are demonstrating a powerful presence. If the warming trend continues, people living in northern New England may see more cases of Lyme disease as well.

The New England Regional Assessment Report cited similar climate trends as we have in their 1895-1999 study period, but the NERA used regional data already processed by the National Climate Data Center. We used data directly from the specific stations, reported to the Northeast Regional Climate Center. NERA published a 1.7º C increase in Rhode Island winter temperature as compared to a 1º C increase found in this study; NERA also found a 1.3º C increase in Rhode Island summer temperature, which is greater than the nearly 1º C increase we found. There are not many NCDC stations in Rhode Island, and only one, Kingston, RI, that has data going back to 1926. With the smaller, station specific data analysis, a much smaller degree of change was observed, yet the warming trend was observed nonetheless.

In this study, we have examined key climate variables that influence the presence of Lyme disease in the northeastern United States. The focus was on whether we could see a warming trend at the regional level using local climate stations and whether this information could be extrapolated to a vector's staying power. We found an increase in temperature, particularly in Rhode Island and Massachusetts, suggesting climate change along a latitudinal gradient as opposed to a diffuse trend. Increases in temperature across all months except January were evident. No clear explanation for the cooling January tendency has been asserted here, but milder Decembers often lead to cooler Januaries. There have been increases along the variables for mean minimum temperature, mean temperature and mean maximum temperature in all three states except for a decrease in winter maximum temperatures. Finally, summer precipitation has risen along the transect and declined for winter precipitation.

In conclusion, several aspects of the study should be considered for future research. The small number of climate stations does provide a source of error. There is also great variability among coastal and inland, latitude, and urban and rural sites. The data was calculated based on individual sites instead of using a spatial summation. An assumption made here was that the climate variables (mean temperature, mean minimum temperature, mean maximum temperature, total precipitation) were adequate to demonstrate a significant trend warming New England. A future study could involve investigating climate, disease incidence, and the *Ixodes* spatial distribution throughout the region across time. Current attempts to use climate as a predictor for tick distribution are limited. With increased surveillance of the black-legged tick and continued CDC monitoring of cases, which only started around 1991, a climate-based distribution model of *Ixodes* ticks and Lyme transmission could be developed.

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- Jason Allard

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- Jason Roy
- Susan Subak
- Albert Wessen

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- Disco Inferno
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