The Effects of Climate Change on Tick Habitat Suitability and Potential Transmission of Lyme Disease in the South Central U.S.

Quiana Berry
Bronx Community College, NYC

Adrienne Wootten, Derek Rosendahl and Renee McPherson
South Central Climate Adaptation Center, Norman, OK

ABSTRACT

Lyme disease is the most prevalent arthropod borne disease in the United States. The disease is transmitted to humans and other mammalian hosts through the bite of infected ixodes scapularis, better known as black-legged ticks. Established tick populations were historically reported in Eastern and Central United States. However, projections of climate change in North America suggest an increase in distribution of tick habitat suitability and subsequent Lyme disease incidence in the future. Future climate model projections serve as important tools because they can account for various future scenarios of how tick habitat suitability might change. The outcome of this research was to identify habitats of black-legged ticks by creating a logistic regression utilizing historical modeled climate data and tick data to determine future tick habitat suitability across the U.S. Tick presence was found to increase along the Gulf Coast of Texas and decrease in Oklahoma. These results can help guide the appropriate targeting of prevention efforts against populations who may be at risk of Lyme disease contraction within the South Central U.S.

1. INTRODUCTION

The World Health Organization (WHO) reports that there are more than 1 billion cases and more than 1 million deaths from Vector Borne Diseases (VBDs) annually. VBDs, including but not limited to Lyme disease, account for more than 17 percent of all infectious diseases. Lyme disease is the most prevalent vector borne disease with more than 100,000 cases reported since 1982 (Orloski et al., 2000) Compared to any other arthropod vector on earth, ticks transmit a greater diversity of viral, bacterial and protozoan diseases (Jongejan and Uilenberg, 2004; IOM, 2011). Ticks not only affect humans, but they also affect the production of over 1 billion cattle and a similar number of sheep around the world. Health departments in each state across the U.S. and the District of Columbia report approximately at least 30,000 cases of Lyme disease annually. Not all cases in the United States are reported and the actual number of cases per year may be up to twelve times higher according to following source(https://www.cdc.gov/media/releases/2013/p0819-lyme-disease.html). Climate change is expected to cause a redistribution of the vector *ixodes scapularis*, better known as the black-legged tick. For this reason, research into vector borne diseases is crucial to finding more efficient ways to protect ourselves against a new wave of black-legged ticks that could potentially be exacerbated by a changing climate.

Understanding where ticks are located and how they operate will better inform preventative measures taken within communities. Ticks are not insects but rather complex arachnids or small joint-legged animals, relatives to spiders. For the purpose of this paper I will focus on the black-legged tick which are native to the U.S. Black-legged ticks go through four life stages: egg, six-legged larva, eight-legged nymph and adult. After larvae have hatched from the eggs and have fed, they drop off the host and molt to nymphs. Nymphs reemerge the following late spring just before the new generation of larvae hatch. Ticks are not born infected with pathogens, but can become infected after feeding upon an infected host. Ticks must consume blood at every stage to survive, however, most will not complete their life cycle if they don't encounter a host in time for their next feeding.

Climate change can have an impact on tick populations by speeding up and extending tick life cycle, causing an acceleration in development, thus sparking an increase in the output of eggs which increases the tick population and therefore can potentially change the risk of lyme disease contraction. When infected black-legged ticks feed on humans they can infect us with many diseases such as: *babesiosis, anaplasmosis*, *Borrelia miyamotoi* infection, Powassan virus in addition to Lyme disease. Of the aforementioned diseases I will focus on the potential for transmission of Lyme disease. Lyme disease or Lyme borrelia is caused by the bacterium *Borrelia burgdorferi.* If left untreated, infection can spread to joints, the heart and the nervous system according to the Center for Disease Control (CDC). In order to prevent the onset of Lyme disease, prevention through reducing exposure in areas infected ticks inhabit is essential. The regions black-legged ticks inhabit currently are primarily in the eastern and northern United States (Figure 1a., Eisen et al. 2016).

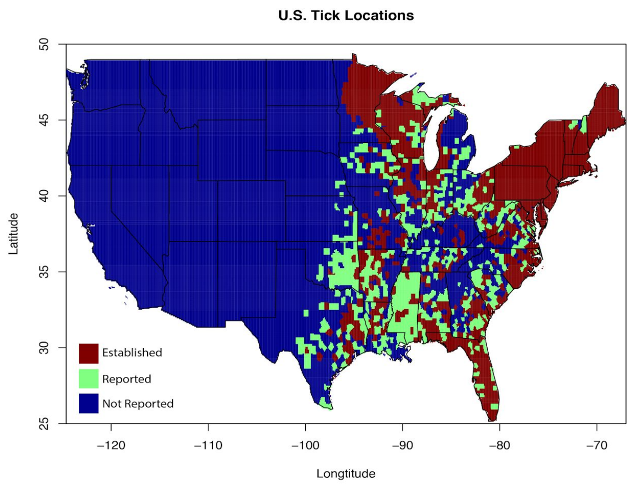

Figure 1.*-Map of Tick Established vs. Reported regions based from (Eisen et al. 2016)*

In addition to climate the incidence of Lyme disease is tied to ecological factors such as "forest fragmentation, vegetation, adult tick hosts."(Halos et al. 2010) Climate fluctuations affect the ecological needs and the seasons in which the tick life cycle operates. Understanding the relationship between how ecology and climate affects ticks allows us to better predict their patterns of movement. Ticks rely on specific conditions related to climate such as a humidity rate of >85% and air temperatures of >6°C to 7°C (Süss et al.2008). Other climate variables that serve as significant predictors of nymphal activity are near-ground temperature, day length and relative air humidity (Daniel et al. 2015). Studies indicate that ticks do not survive when exposed to dry air for long periods while constant humid air has a large positive impact on tick survival. (Rodgers et al. 2007) Additionally, questing activity or the act of seeking hosts, was reduced by hot, dry summer weather, therefore decreasing nymphal ability to feed and mature (Burtis et al. 2016). Ticks scope out their environment by using their thermoreceptors to sense microclimates that will be most suitable for them (Süss et al.2008). Certain regions supply more suitable conditions for ticks to flourish more than others. For an example, the northeastern U.S. provides the adequate temperature and humidity necessary for tick survival.

In this study, I will examine how the potential for suitable regions for tick habitat may expand into the South Central U.S. under and changing climate. Previous studies have analyzed projections of tick populations for specific regions of North America using predominantly one type of model for climate projections. Autologistic regression modeling has been utilized with climate data downscaling to the 0.5th degree. I used MACA Livneh which has a resolution of 6-km (1/16th degree) corresponding to the United States. Additionally other studies have researched different regions of North America on a microscopic scale or have looked on a macroscopic scale at all of North America or Canada. This study focuses on the tick distribution on a local scale within national parks and cities of the South Central region of the U.S.

2. MATERIALS AND METHODS

To project future tick habitat suitability in the South Central U.S. The programming language R version 1.1.453 was used to import, analyze and graph gridded tick and climate data. The first step consisted of extracting historical tick establishment data for our 51 parks and cities of interest in the South Central U.S. based on Eisen et. al (2016).

Some example locations include, but are not limited to Oklahoma City, OK, Chickasaw National Recreational Area in Oklahoma, St. Louis, MO, Houston, TX, Cimarron National Grassland in Kansas, Cane River Creole National Historical Park in Louisiana (Figure 2). Next, the monthly observation-based historical climate data, historical climate model output and future climate model output were gathered for the same 51 locations. The monthly variables included the monthly maximum temperatures (MaxTmax), monthly mean temperatures (Tmean), monthly minimum temperatures (MinTmin)and monthly total precipitation (Precip). Since there was one value for tick data and a monthly time series for climate data, the historical observations and climate model output were condensed down to a set of numbers that could be directly related to the tick data by calculating the mean, maximum, minimum and standard deviation of each monthly climate variable. The historical time period used was 1950-2005 while these calculations were repeated for future climate model output for the period 2070-2099. Logistic regression was utilized for the predictive analysis to build a relationship between tick presence and climate data. There are 16 climate variables used as predictors for the logistic regression, including mean of MaxTMax and mean of Precipitation (Table 1). Furthermore, my categorical variable was yes or no (0 or 1 for mathematical simplicity) in reference to tick presence or absence at each of the 51 locations. For the logistic regression, tick data was substituted as the predicatand and the 16 climate variables served as predictors. The likelihood of tick presence was predicted based on the observation-based historical climate data and historical model output. Afterward, the logistic regression created with the historical model output is used to determine the future probability of tick presence with the future climate model output. Finally, the probabilities based on the historical and future climate model output established at the locations of interest are used to determine the change in tick habitat suitability in a changing climate. For the calculations the observation-based historical climate data used were from the **Livneh v. 1.2** gridded climate data (Livneh et al. 2013). The climate model output used is downscaled Community Climate System Model version 4 (CCSM4, Gent et al. 2011) from Representative Concentration Pathway 8.5 (RCP 8.5, van Vuuren et al. 2011; Riahi et al. 2007) simulations used in the Coupled Model Intercomparison Project Phase 5 (CMIP5, Taylor et al. 2012) archive. The downscaling was done using the Multivariate Adaptive Constructed Analogs version 2 (MACAv2-LIVNEH, Abatzoglou et al. 2012). All the downscaled climate model output used for this study was downloaded from the Northwest Knowledge Network (https://www.northwestknowledge.net/home).

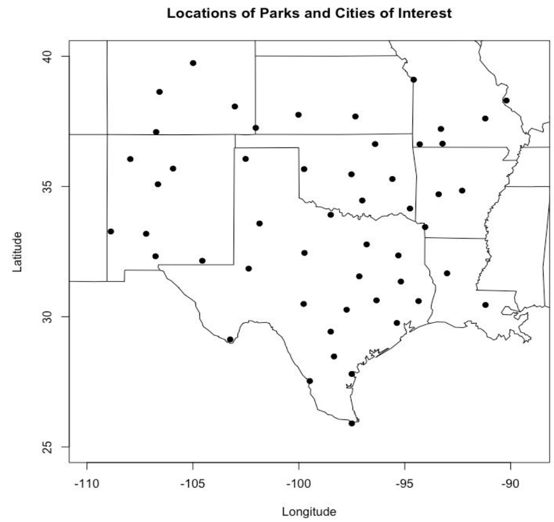

Figure 2 *- Select Locations in the South Central U.S.*

3.RESULTS AND DISCUSSION

My results use the derived relationship between tick and climate data to project climate based habitat suitability of black-legged ticks in the future. Historical and future probability maps of tick presence were generated from climate model data. From the historic to the future probability maps (Figure 1b.), we will see there is a decrease in tick presence in Oklahoma and an increase in tick presence in Southern Texas.

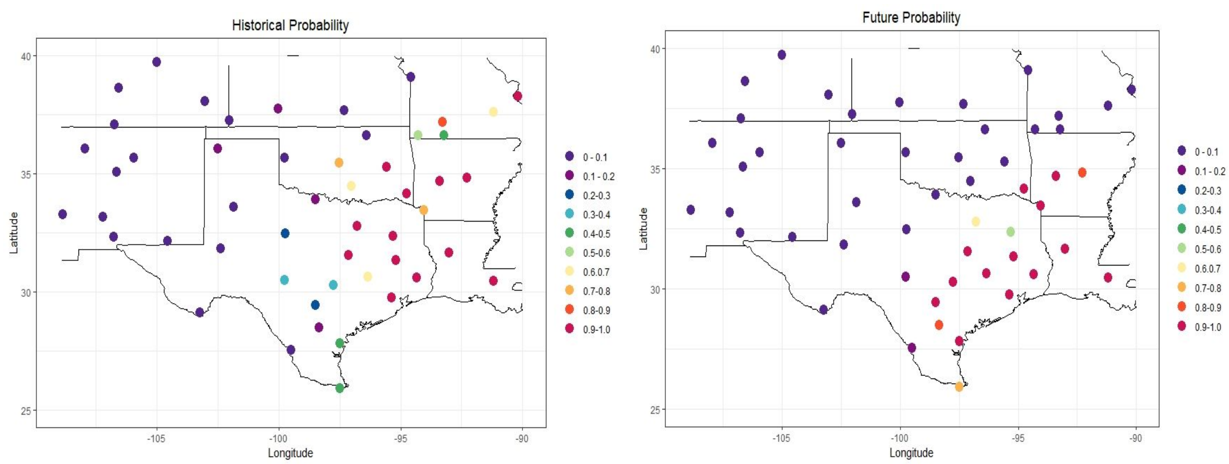

Figure 3. *Maps of historical (left) and future (right) probability the habitat of each location is suitable for blacklegged ticks.*

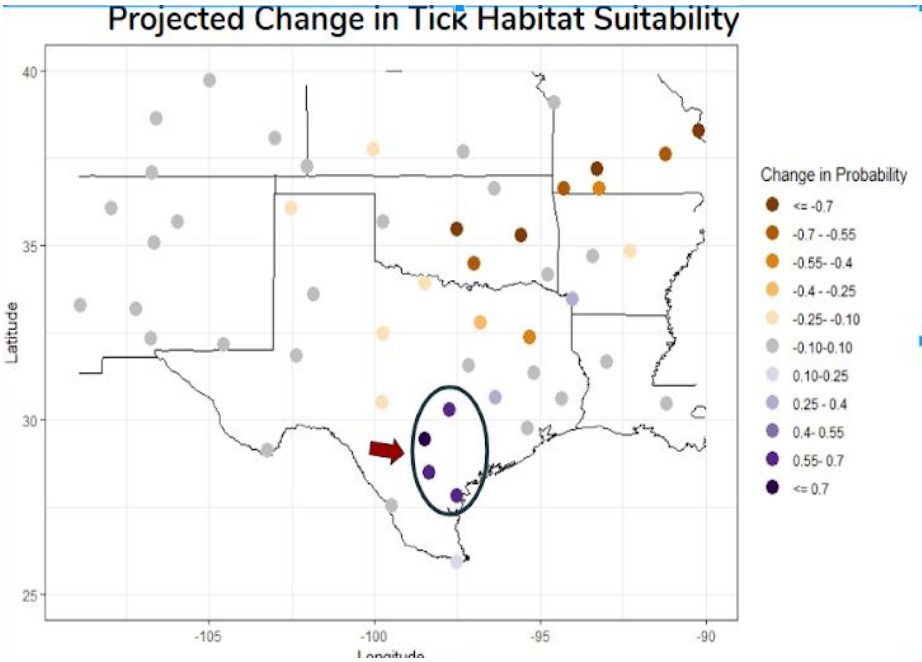

***Figure 4**. Projected Change of Tick Habitat Suitability for the South Central United States.*

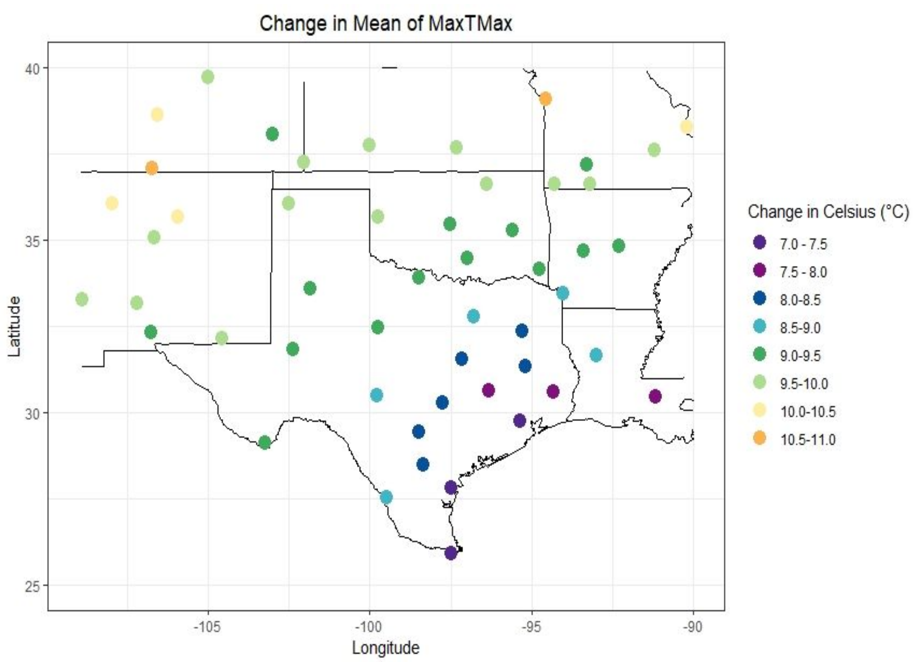

***Figure 5.** Projected Change of Mean of MaxTmax at each location in degrees Celsius.*

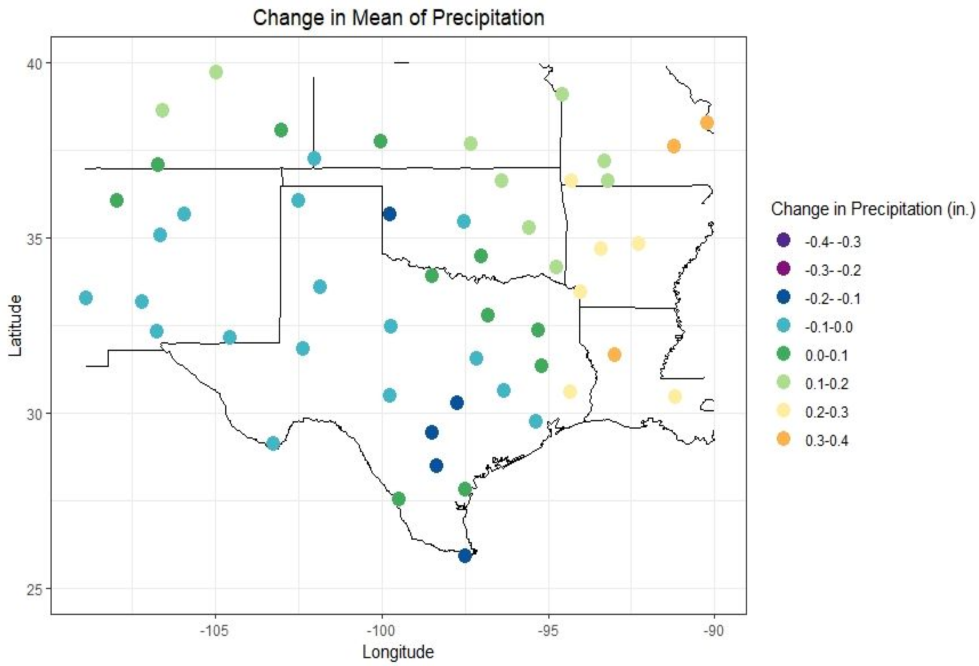

Figure 6. *Projected Change of Mean of Precip at each location in inches.*

Short name	Definition
Max of MaxTmax	Maximum of monthly maximum temperatures
Mean of MaxTmax	Mean of monthly maximum temperatures
Min of MaxTmax	Minimum of monthly maximum temperatures
SD of MaxTmax	Standard Deviation of monthly maximum temperatures
Max of Tmean	Maximum of monthly mean temperatures
Mean of Tmean	Mean of monthly mean temperatures
Min of Tmean	Minimum of monthly mean temperatures
SD of Tmean	Standard Deviation of monthly mean temperatures
Max of MaxTmin	Maximum of monthly minimum temperatures
Mean of MaxTmin	Mean of monthly minimum temperatures
Min of MaxTmin	Minimum of monthly minimum temperatures
SD of MaxTmin	Standard Deviation of monthly minimum temperatures
Max of Precip	Maximum of monthly total precipitation
Mean of Precip	Mean of monthly total precipitation
Min of Precip	Minimum of monthly total precipitation
SD of Precip	Standard Deviation of monthly total precipitation

Table 1-*Climate Variables utilized in logistic regression.*

The difference of historical climate model probability and historical tick probability was positive or negative depending on the location. After calculating the probability of the presence or absence of ticks in various states across the U.S. alongside a changing climate, the verdict is that the presence of ticks both increases and decreases depending on the given area. The areas of increased tick habitat suitability risk is in Southern Texas and the area of decreased risk is across Oklahoma (Figure 2). Figure 2 summarizes and merges the historical and future probability maps into one, showing the areas of concentrated increase in tick presence on the Gulf Coast of Texas and concentrated decrease in Oklahoma. I will utilize Figure 2 as a reference of comparison against climate variables Mean of MaxTMax and Precipitation. In the maps, the change in temperature ranging from 7.0-8.5 °C mean of MaxTMax (Figure 3) corresponds to the increased area of tick suitability (Figure 2) in the Gulf Coast of Texas of ≥0.7. The surrounding area is increasing in temperature and therefore decreasing in tick suitability. The temperature increase of 7.0-8.5°C leave the region with favorable conditions necessary for ticks to thrive relative to the surrounding areas of greater temperature increase and thus decreased tick suitability.

The change in precipitation ranging from -0.2-0.1 inches (Figure 4) corresponds to the increased area of suitability(Figure 2) in the Gulf Coast of Texas. The surrounding area is increasing in precipitation, but also has a greater increase in temperature. This leads to increased rates of evaporation and loss in moisture in the atmosphere. Therefore in the area of Southern Texas it is not projected to increase, but the temperature is also not projected to increase as much as the surrounding regions. Consequently, relative to its surroundings, the area of Southern Texas will have more stability in temperature and moisture, making the habitat more suitable for ticks . For this reason, the surrounding region is less likely to have suitable tick habitat in the future compared to the Gulf Coast of Texas. It is important to note that although climatic conditions impact tick habitat suitability, multiple factors including climate can affect tick habitat suitability. This study attempted to further elucidate the relationship between climate and tick habitat suitability so that the necessary prevention measures could be taken in affected areas.

4. CONCLUSION

It is evident that both the climate and the environment have a profound impact on tick behavior, habitat suitability and development. As vector-borne diseases, like lyme disease, continue to increase, it is of utmost importance that we account for potential areas at risk as the distribution of vectors like black-legged ticks continue to proliferate in new regions across North America. Between the two major climate variables used in this study, temperature and precipitation, temperature has a stronger influence over tick habitat suitability. Furthermore, as seen in the future projection maps there is an overall decrease in tick habitat suitability in Oklahoma and a significant increase in tick habitat suitability along the Gulf Coast of Texas because there is a slight projected increase in temperature with a small projected change in precipitation. In contrast, other locations are projected to have a much larger increase in temperature, causing a sharp projected increase in evaporation and leading to a sharp projected decrease in moisture. The slight increase in temperature along the Gulf Coast of Texas causes a slight loss in moisture, which leaves this region as a more suitable habitat for black-legged ticks. In the surrounding regions, the larger increase in temperature, leads to larger decrease in moisture, reaching a point where the regions are no longer a suitable habitat for ticks. Finally, the downscaled CCSM4 model output used in this study is different from the climate information used in prior studies. The results in this study are different in part because of the climate model output used, this highlights the fact that using more than one model is important for formulating a comprehensive view of future probability.

5. ACKNOWLEDGMENTS

This research was funded by the National Science Foundation under Grant No.AGS-1560419. I would like to thank Daphne LaDue, the Research Experience for Undergraduates (REU) program and the South Central Climate Adaptation Center (SCCASC) for this opportunity to conduct research. I would also like to thank Adrienne Wootten for assistance with coding, data manipulation, editing and generating maps. Also, I would like to thank Derek Rosendahl and Renee McPherson who have also provided helpful advice throughout the research process.

6. REFERENCES

Abatzoglou, J. T., and T. J. Brown, 2012: A comparison of statistical downscaling methods suited for wildfire applications. *Int. J. Climatol.*, **32**, 772–780, doi:10.1002/joc.2312.

Burtis, James C., et al. "The Impact of Temperature and Precipitation on Blacklegged Tick Activity and Lyme Disease Incidence in Endemic and Emerging Regions." *Parasites & Vectors*, BioMed Central, 25 Nov. 2016, parasitesandvectors.biomedcentral.com/articles/10.1186/s13071-016-1894-6.

Daniel M, Malý M, Danielová V, Kříž B, Nuttall P. Abiotic predictors and annual seasonal dynamics of *Ixodes ricinus*, the major disease vector of Central Europe. *Parasites & Vectors*. 2015;8:478. doi:10.1186/s13071-015-1092-y.

Dennis DT, Nekomoto TS, Victor JC, Paul WS, Piesman J. Reported distribution of *Ixodes scapularis* and *Ixodes pacificus* (Acari: Ixodidae) in the United States. J. Med. Entomol. 1998;35:629–638.

Eisen, R. J., Eisen, L., & Beard, C. B. (2016). County-Scale Distribution of *Ixodes scapularis* and *Ixodes pacificus* (Acari: Ixodidae) in the Continental United States. *Journal of Medical Entomology*, *53*(2), 349–386. http://doi.org/10.1093/jme/tjv237

Halos, Bord et al. "Ecological Factors Characterizing the Prevalence of Bacterial Tick-Borne Pathogens in Ixodes Ricinus Ticks in Pastures and Woodlands." *Applied and Environmental Microbiology*, American Society For Microbiology, 1 July 2010, aem.asm.org/content/76/13/4413.full.

Gent, P.R., G. Danabasoglu, L.J. Donner, M.M. Holland, E.C. Hunke, S.R. Jayne, D.M. Lawrence, R.B. Neale, P.J.Rasch, M. Vertenstein, P.H. Worley, Z.-L. Yang, and M. Zhang, 2011: The Community Climate System Model Version 4. *J. Climate*, **24**, DOI: 10.1175/2011JCLI4083.1

K. Rose, 2011: The representative concentration pathways: an overview. *Climatic Change*, **109**, DOI: 10.1007/s10584-011-0148-z

Livneh B., E.A. Rosenberg, C. Lin, B. Nijssen, V. Mishra, K.M. Andreadis, E.P. Maurer, and D.P. Lettenmaier, 2013: A Long-Term Hydrologically Based Dataset of Land Surface Fluxes and States for the Conterminous United States: Update and Extensions. *J. Climate*, **26**, 9384–9392, DOI: 10.1175/JCLI-D-12-00508.1

Riahi, K., A. Grubler, and N. Nakicenovic, 2007: Scenarios of long-term socio-economic and environmental development under climate stabilization. *Technological Forecasting and Social Change*, **74**, DOI: 10.1016/j.techfore.2006.05.026

SE, Roger, et al. "Duration of Exposure to Suboptimal Atmospheric Moisture Affects Nymphal Blacklegged Tick Survival." *Parasites & Vectors*, J Med Entomol, 2007, www.ncbi.nlm.nih.gov/pmc/articles/PMC4650338/.

Süss, Jochen, et al. "What Makes Ticks Tick? Climate Change, Ticks, and Tick-Borne Diseases." *Freshwater Biology*, Wiley/Blackwell (10.1111), 21 Jan. 2008, onlinelibrary.wiley.com/doi/full/10.1111/j.1708-8305.2007.00176.x.

Taylor, A., J. M. Gregory, M.J. Webb, and K. E. Taylor, 2012: Forcing, feedbacks and climate sensitivity in CMIP5 coupled atmosphere-ocean climate models. *Geophysical Research Letters*, **39**, DOI: 10.1029/2012GL051607

Van Vuuren, D.P., J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard, G.C. Hurtt, T. Kram, V. Krey, J.-F. Lamarque, T. Masui, M. Mainshausen, N. Nakicenovic, S.J. Smith, and S.