Environmental and Spatial Determinants of Lyme disease

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Abstract:

Lyme disease is the most prevalent vector borne disease in the United States accounting for over 30,000 annual reported cases (Yale, 2016). Lyme disease is a public health crisis that costs the U.S. Healthcare system between 712 million -1.3 billion annually (Science News, 2015). If cases could be reduced by learning about spatial effects of Lyme disease possible countermeasures could be deployed to control the size and scope of this epidemic. People who contract this disease feel chronic arthritic pain as well as nervous system and heart related problems. Many times it is thought to be chronic fatigue or other autoimmune ailments (CDC, 2016). The lack of immediate medical treatment with antibiotics can lead to permanent disabling health problems. Currently, no vaccines exist to combat Lyme disease and testing is often inaccurate. According to lymedisease.org, 56% of patients are misdiagnosed as negative with the two-tiered testing process recommended by the CDC (Striker, 2007). The exploration of significant factors could lead to predictive mapping of this disease within the United States and reduce its costly toll. The geographic study area includes Vermont, New York and Pennsylvania. These three states while sharing borders along the Northeast part of the United States, have varying degrees of Lyme disease cases. Vermont reported 442 cases, New York with 2853 and Pennsylvania had 6470 Lyme disease cases in 2014 (CDC, 2016). This region contains contiguous states that share similar types of regional environmental effects but have varying degrees of Lyme disease cases. Pennsylvania has over 16.7 million acres of forest land or 60% of the state, Vermont has 4.6 million acres or 78% and New York has 19 million acres or 63% of the state (USDA, 2014). The pattern seen today is increased housing density in more rural forested counties and a fragmentation of forests over time. This results in the creation of more forest edges and a change in the environmental makeup of these areas. An exploration into what variations within this geographic area accounts for the variation of Lyme disease cases found. Are factors such as white-tailed deer range areas, tick friendly environmental conditions, and the expansion of human populations into rural community's possible explanations? White-tailed deer are an important host for ticks as they carry them to various locations. They provide an important transportation method in expanding ticks to newly infected areas.

I want to show how using point data for Lyme cases and factors such as white-tailed deer, human population, or climatic changes can be used as a predictive model for Lyme disease. The ability to predict were these cases will be spread can help prepare prevention measure for those communities. Geographic Information tools provide a way to measure environmental variables and events associated with them. The use of Tobler's First Law of Geography that "everything is related to everything else, but near things are more related than distant things" is cornerstone for spatial research (Tobler, 1970). It provides perfect method in which Geographic Information Systems (GIS) can help analyze factors in space and time for causation. John Snow's examination of the cholera outbreak in Soho, London showed how epidemiology and GIS spatial cluster analysis can be a great investigative tool. The research question that guides this research is: What environmental factors, at a county level, relate to the incidence of Lyme disease? The hypothesis is that with climate change and movement of white-tailed deer ticks these factors are contributing to the spread of Lyme further into regions never seen before.

I would like to examine the effects of suburban sprawl on higher rates of infection of tick borne viruses. I would like to correlate population growth areas, soil types and deer populations with yearly point data for Lyme disease cases for the past 3 years. The

likelihood is that human encroachment has caused a higher rate of infection along reforestation zones. Deer populations now thrive in residential backyards and from effects of reforestation. They have grown in population from the 1930s of 300,000 to over 30 million today (Koryos, 2014). Deer's natural predators have been driven mostly to extinction and reforestation efforts have allowed them to flourish (Koryos, 2014). I would like to explore all these contributing factors on the Lyme disease rate and examine the factors within each of these counties that contribute to the alarming rising incidence rates. The result will provide a model to track and predict Lyme disease incidences based on significant environmental factors.

Literary Review:

Reviewing literature on Lyme disease and spatial determinants was done to give a complete history on efforts done with this topic. The review of previous studies produced information that helped in my research of this topic are below.

A. A Climate-Based Model Predicts the Spatial Distribution of the Lyme Disease Vector Ixodes scapularis in the United States. John S. Brownstein, Theodore R. Holford, and Durland Fish. Source: Environmental Health Perspectives Volume. 111, No. 9 (Jul, 2003), pp. 1152-1157 Accessed: 4/04/2016 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2582486/

This study looks at spatial distribution of black-legged deer ticks and how seasonal temperature and humidity climate affect tick species. A logistic model is developed to predict expansion and establishment of tick populations using mean, minimum and maximum temperature data as well as vapor pressure by month over period 1960-1990. Each grid of .5 degree pixels were calculated using cell statistics. The model was able to determine habitat suitability and predict emerging and future patterns of tick distribution. This research demonstrated that climatic extremes and vapor pressure were strong predictors of habitat suitability.

B. Environmental Risk Factors for Lyme disease Identified with Geographic Information Systems. Gregory Glass, PhD., Brian S. Schwartz, MD, MS, John M. Morgan III. PhD, Dale T Johnson, MA. Peter M. Noy and Ebenezer Israel MD. Source: American Journal of Public Health Vol. 85 No. 7 (July, 1995), pp 944-948 Accessed 05/05/2016 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1615529/

The study examined 11 environmental factors in the Baltimore County area associated with Lyme disease. The study showed residence in forested areas, soils, land cover, near watershed areas and slope elevation played a statistically significant factor in risk of Lyme disease. The GIS model showed that residence or spatial determinants play a pivotal role in risk for tick contact.

C. Exploratory spatial analysis of Lyme disease in Texas-what can we learn from the reported cases? Barbara Szonyi, Indumathi Srinath, Maria Esteve-Gassent, Blanca Lupiani and Renata Ivanek. Source: BMC Public Health (2015) 15:924 DOI 10.1186s12889-015-2286-0 Accessed 05/15/2016 http://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-015-2286-0

This study reviewed the positive autocorrelation of Lyme disease in Texas and the geographic significance of environmental ecosystems. These correlated to high clustering counties were determined by using a Local Indicators of Spatial Association. Clusters were found in ecosystems thought not to be friendly to tick development in the Cross-Timbers region of central Texas. The results highlight ecosystem diversity in this region as an explanation for the influence of host populations on ticks.

D. Analyzing the Correlation between Deer Habitat and Component of Risk for Lyme disease in Eastern Ontario, Canada: A GIS-Based Approach. Dongmei Chen, Haydi Wong, Paul Belanger, Kieran Moore, Mary Peterson, and John Cunningham.

Source: ISPRS International Journal of Geo-Information (January 15, 2015) Retrieved 04/25/2016
http://gis.geog.queensu.ca/LaGISAWeb/PublicationPDFs/2015ijgi-Lyme-00105.pdf

The study focused on the association of a weighted deer habitat suitability model and deer harvest data with Lyme cases in Ontario, Canada. The results showed between 2006 and 2012 a positive correlation between deer migration and tick populations showed a northern expansion observed. The results showed that deer habitats provided strong correlation for tick suitability. These factors included mixed forest, slope, water proximity and over 3 miles from urban areas.

Data:

Lyme disease cases come from the Center of Disease Control (CDC) and contain the last ten years from 2005-2014. I also acquired rainfall, climate and NDVI canopy cover data for each county in my study area from the National Oceanic and Atmospheric Administration (NOAA). Rural or non-rural county data came from the United States Department of Agriculture (USDA). The Deer density data for white-tailed deer ranges was provided by USDA. Soils, ecosystem and land cover data was provided by the Unites States Geological Service (USGS). Census level data was aggregated at county level from the Census Bureau. This data contained demographic and population information for the study area. Data from these sources were compiled and merged with a corresponding U.S. contiguous shape file (Esri, YEAR). This base map will be a contiguous map of Northeast United States with 143 counties spatially joined to data by the Federal Information Processing Standard (County-FIPS). I will be focusing on three states with high, medium and low incidence rates to determine what environmental factors create county level Lyme disease effects. Table 1 summarizes the data sources and types of shapefiles used for this Lyme disease analysis.

Table 1 Data Sources for Lyme disease Analysis

Data Layer	Source	Data Type
Raw Count Lyme Cases County	Center for Disease Control and Prevention (CDC)	Excel/Polygon
Soils Data (PH, Depth, Type)	United States Agriculture Department (USDA)	Polygon
Deer Density	Quality Deer Management Association	Polygon
Recreation Sites	US Forest Service	Polygon
Population Density/% Change	US Census Bureau	Polygon
Building Permits/Housing Units % Change	US Census Bureau	Polygon
Elevation/Slope	United States Geological Survey (USGS)	Raster/DEM
Temperature/Precipitation/Humidity/Snow	USGS	Polygon
Canopy Cover/Proximity Forest Edge	National Oceanic and Atmospheric Administration (NOAA)	NDVI/Raster
Watershed Percentage County	USGS	Raster

Methods:

My approach would be to create a geodatabase of independent variables and use regression model to correlate the cause and effect for Lyme disease cases in my study area for the last three years. I will average Lyme disease cases in each county over last 3 year period to see how significant counties have been affected by Lyme disease. This will allow me to analyze the most current Lyme disease patterns for these counties. A county level analysis of independent factor such as deer density, soils, rural encroachments and other factors will be reviewed against aggregated county level Lyme cases. I will use a Lisa Cluster map to project high and low risk county areas for Lyme disease using a rook neighbor method. I will correlate these plots and use Ordinary Least Squares (OLS) regression model in ArcMap as well as Geographically Weighted Regression models to analyze independent variables for significance on Lyme disease incidences. The models will be reviewed and the results discussed.

My initial efforts were spent in acquiring data and joining them spatially to the respective County-Fips codes. Next, the Lyme Disease County data was geocoded and quality checked so they matched one of the 143 counties. I had issues in getting some data and making determination on other data sets for relevancy and redundancy.

I used CDC Lyme disease county data for these three US states to show expansion of Lyme disease for the past three years. I wanted to examine each factor closer in connections with counties that showed the most statistically significant results. A cluster analysis was performed on the data to examine significance of Lyme disease to these spatial areas or counties. The county data was smoothed for population and rates were per 100,000. This allowed for a standardized comparisons across counties for incidence rates.

Map showing spread of Lyme disease across the US over the past ten years. Maps related to examine Lyme disease and the four independent variables I want to explore. These are the white-tailed deer, human sprawl, environmental and climate effects. I created overlay maps to examine closely how these factors relate to Lyme disease patterns. I used regression analysis to test how important each factor is in the determination of deer tick populations in these three States. I also want to examine the role each plays in the increased or decreased infection rates of counties. A choropleth map outlining future areas that contain habitats that could sustain the deer tick populations based on environmental trends could be helpful in taking counter measures against ticks in those locations. These counter measures include warning signs and application of tick control pesticides. The ability to create awareness in these areas could reduce infection rates and future medical costs.

Lyme disease Results & Clustering Analysis:

Spatial cluster analysis was performed on the confirmed cases over the period of 2012-2014 to determine if the spatial locations of Lyme cases were distributed randomly over the counties or had statistical significance. A Moran's I and Getis-Ord GI* were conducted on these averaged case for the 3 year period. The results yielded a positive significant nonrandom distribution with 16 counties.

Table 2 shows the 16 significantly high clustered counties with Lyme cases. The table shows the Z-score and P values for the Local Moran's I and Getis-Ord Gi* clustering analysis results. The results form a basis to explore areas that show high results and have neighbors with significant results as well. The overall Global Moran's I Index was .533 z-score of 10.269 with less than 1% likelihood this clustering is from random chance. The Getis-Ord General G results had a z-value of 9.532 and less than 1% likelihood this clustering is from random chance.

Figure 1 & 2 below are cluster maps of the Lyme disease for the Getis-Ord-Gi* and Moran's I. These maps show 2012-2014 smoothed cases for Lyme disease that eliminate population effects. The raw county Lyme cases were divided by county populations to be able to compare per 100,000 incidence rates for all 143 counties. This gives a calculated averaged incidence rate for Lyme disease for each county over a three year period. The data shows increased cases occurring over central parts of Pennsylvania and Southern New York and Vermont increasing since year 2012. During the last three years the virus has trended northeasterly into regions of Vermont and New York. The expansion shows that Lyme disease is established in each of these states and clustering in red counties shown by these cluster maps.

Table 2 Moran's I Values for Counties with Statistically Significant 2012-2014 Lyme Cases

County	State	Cases/100,000	Local Moran's I Z Score	Local Moran's I P Value	Getis-Ord Gi Z Score	Getis-Ord Gi P Value
Windsor County	Vermont	219	2.707	.006	3.885	.0001
Rutland County	Vermont	208	5.243	0	3.783	.0002
Windham County	Vermont	202	5.710	0	4.022	.00006
Bennington County	Vermont	369	8.332	0	4.291	.00001
Washington County	New York	139	2.197	.003	2.909	.004
Rensselaer County	New York	150	2.069	.039	4.078	.000045
Columbia County	New York	312	5.553	0	2.722	.0065
Greene County	New York	310	3.313	.0009	2.430	.0151
Cameron County	Pennsylvania	411	13.471	0	4.647	.000003
Elk County	Pennsylvania	277	6.412	0	5.601	0
Forest County	Pennsylvania	132	2.237	.025	3.366	.0008
Clarion County	Pennsylvania	223	6.913	0	4.146	.000034
Jefferson County	Pennsylvania	409	20.405	0	6.174	0
Clearfield County	Pennsylvania	348	15.877	0	5.312	0
Armstrong County	Pennsylvania	265	7.624	0	3.790	.0002
Indiana County	Pennsylvania	177	3.392	.0007	4.296	.000017

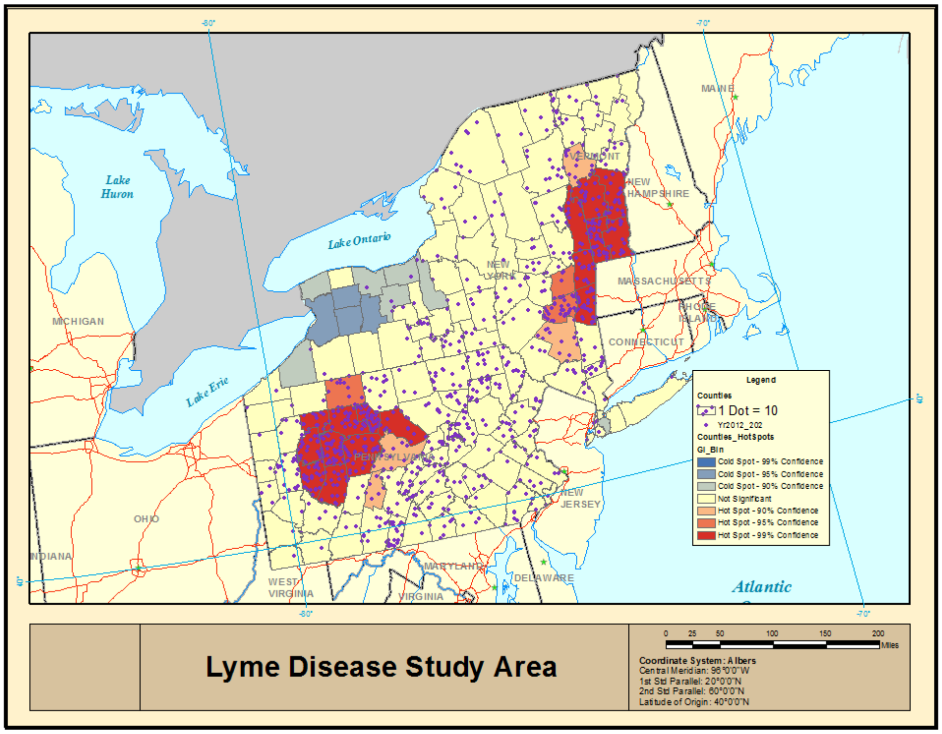


Figure 1 Getis-Ord Gi Cluster Mapping Counties and Lyme disease 2012-2014*

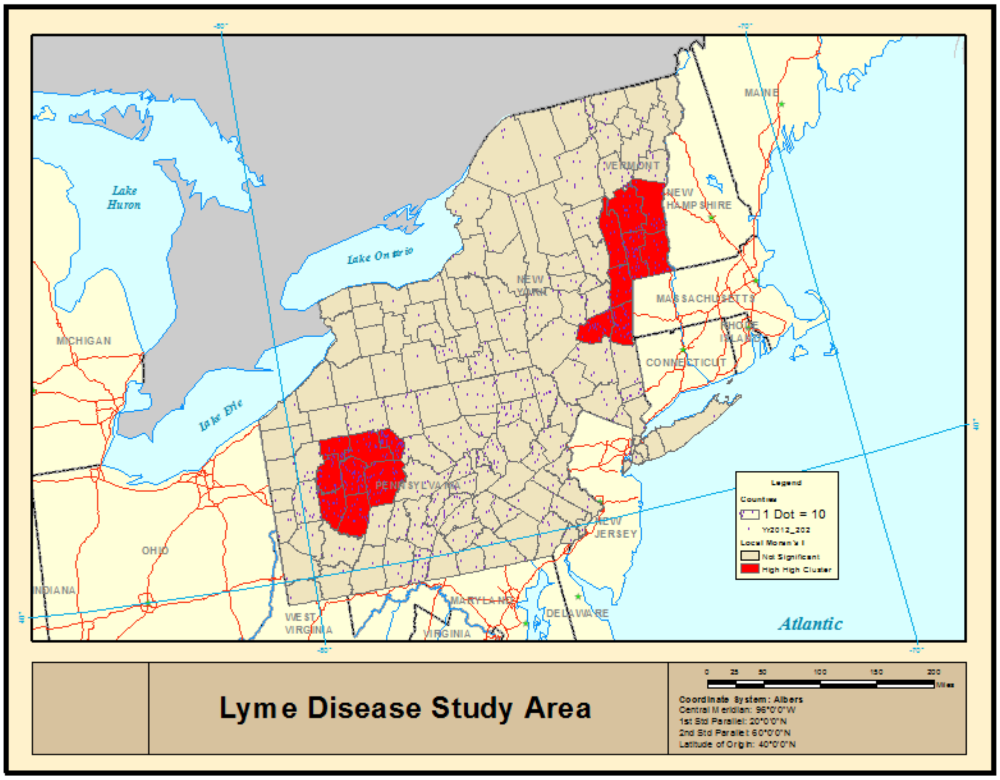


Figure 2 Local Moran's I Cluster Map for Counties and Lyme disease 2012-2014

Local Indicators of Spatial Association (LISA):

Figure 3 below shows results from the LISA Cluster analysis showing that 16 counties in red have high significance ($\alpha = 0.05$) in areas of Eastern New York and Central Pennsylvania. The LISA results also show 25 counties with low significance ($\alpha = 0.05$) in blue that are near large urban areas of New York and along the Great Lakes area. The accompanying Local Moran's I scatterplot results shows evidence of positive spatial clustering with a Moran's I index of .553. These counties should be explored further to examine environmental factors that are statistically significant within each that is contributing to these high or low results. Lyme research done by others has shown a positive correlation to winter temperatures, humidity and white-tailed deer distributions for the spread of the deer tick (Brownstein et al, 2003). The use of spatial regression to check the model of independent variables existing in these counties with Lyme disease results will be used to interpret how much variation is explained by these following factors.

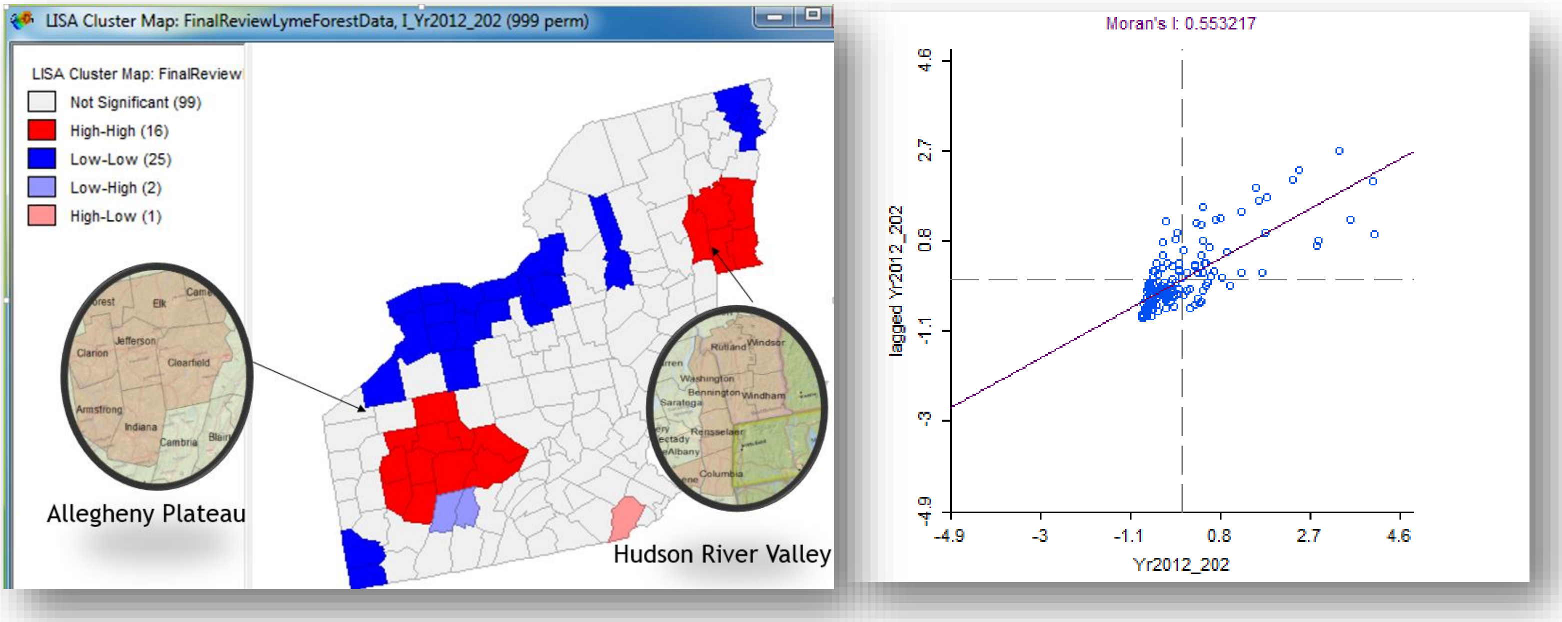


Figure 3 Lisa Cluster Map (α = 0.05) created by GeoDa for Lyme Disease Data using 999 permutations and accompany Local Moran's I result

White-Tailed Deer Populations

Figure 2 below shows the red outlines of significant counties for Lyme disease in our analysis from above overlaid on top of white-tailed deer distribution obtained from the USGS site. This data was georeferenced showing density populations of white-tailed deer throughout the study area. Red outlines are used to show the high significant impact zones for Lyme disease cases over the last 3 years. The results show Lyme case results near forest edges. This could be a result of deer populations being near these areas or people's activities taking them into forested areas near homes. The nearness to river valleys in yellow corresponds to deer populations being close to water sources. These include swaths along the Hudson waterway of New York into Vermont and in the edge of the Allegheny forests in Pennsylvania. It does make sense white-tailed deer are in abundance and feed near forest and river edges. These locations put them into close contact with populations as they distribute new tick larvae in those areas.

Pennsylvania has about 30 deer per square mile at over 1.5 million in the state as of 2014 (DNR, 2014). This is seen as the state has many areas in yellow representing this expansive white-tailed deer population.

Figure 4 below shows deer density map showing areas that cover each of the regions of the three states. Larger portions of counties in NE Pennsylvania and NE New York and Southern counties of Vermont are covered by White-Tailed deer populations or counties with higher densities. These areas are near forested edges and are locations with high dot density representing Lyme cases in purple. The deer density populations range from 15-45 deer per mile. This shows that the white-tailed deer inhabit these forested counties in larger numbers along the edges of the Allegheny and Catskill forests. The areas in Western New York near the Great Lakes have little forestation and could explain the lack of tick populations in these areas as shown this is shown in the canopy percentage map in Figure 5.

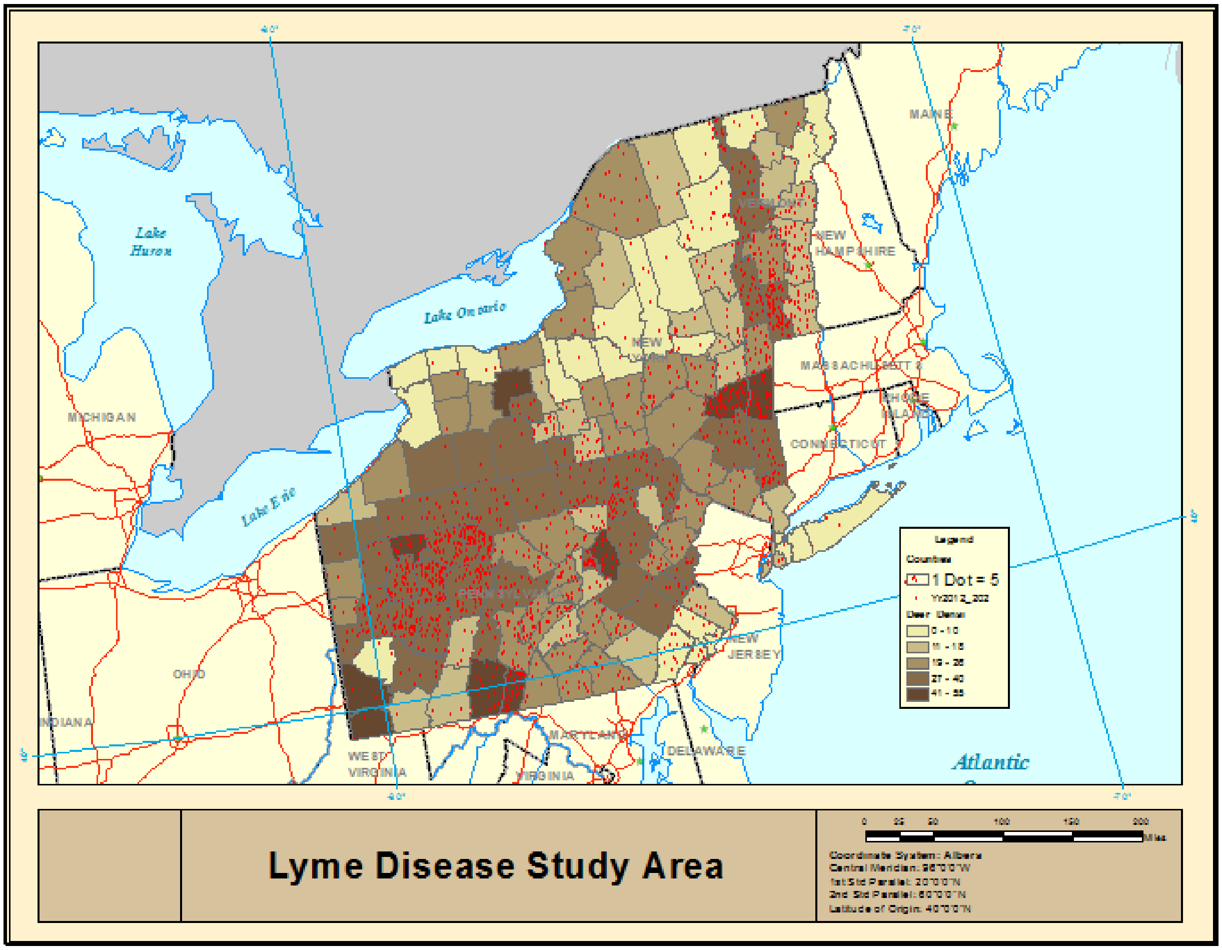


Figure 4 Deer Density Populations per square mile from Quality Deer Management Association

The Lyme disease areas shown below in Figure 5 show propensity for Lyme incidences to occur near denser forest edges in the Hudson Valley and Allegheny Plateau areas. These regions are also site of denser deer population as shown previously in Figure 4. White-tail Deer like to graze near forest edges and by water sources and these areas in grasses are likely were deer ticks latch on to get a "blood meal". These ticks usually rest on tips of grasses and shrubs and a single deer can be the feeding ground for up to 171 adult female ticks from a study done by the Macaulay Land Use Research Institute.

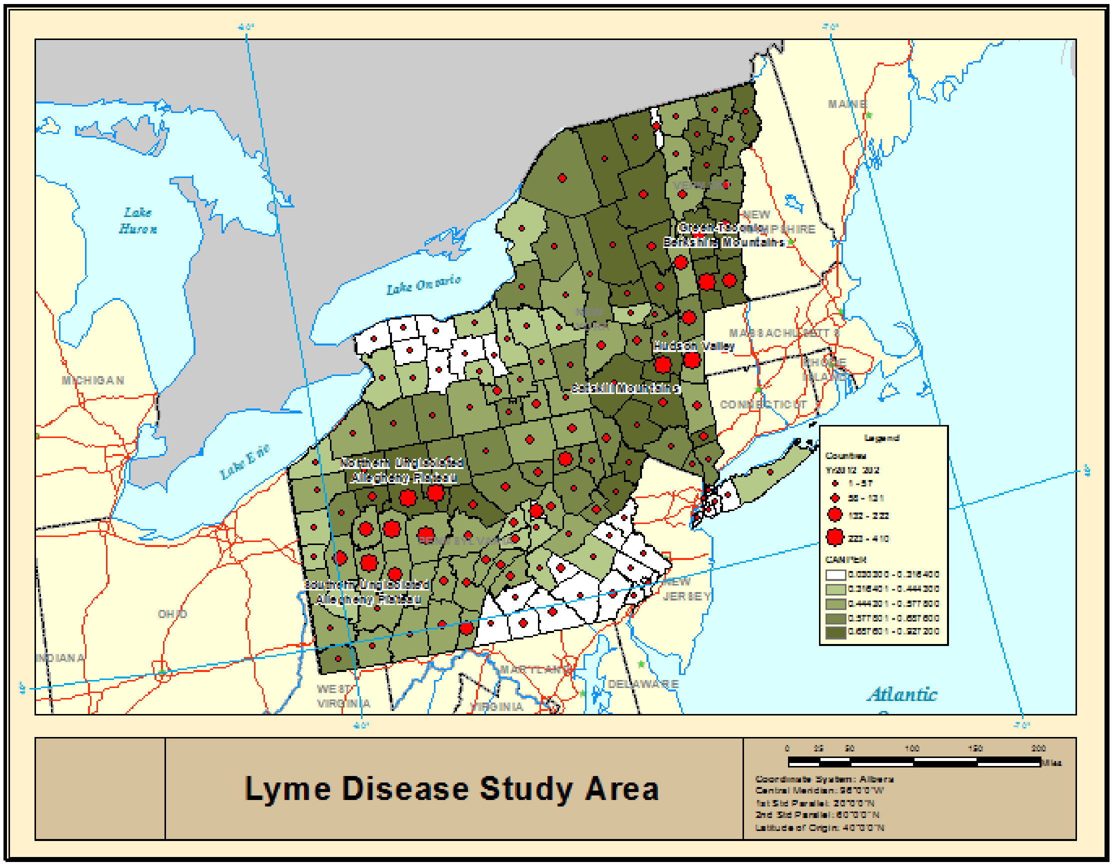


Figure 5 Canopy Percentage of Counties in Study Region Provided by USGS

Rural Population Sprawl (Metro & Rural Counties)

Figure 6 below shows the effects of rural and urban county relationships to Lyme disease. The dark brown areas are 96% rural land based counties. They make up many parts of Vermont, New York and Pennsylvania. The effects of suburban sprawl away from urban areas into near forested areas has enabled more people to be at risk of contact of Lyme disease. Many people also enjoy the outdoor recreational activities their communities provide. Hiking, fishing, hunting all put human hosts into contact with deer ticks. Living within commuting distance to these outdoor pleasure may increase chances for exposure for these residents.

Figure 5 Forest Canopy Percentage County data provided by USGS

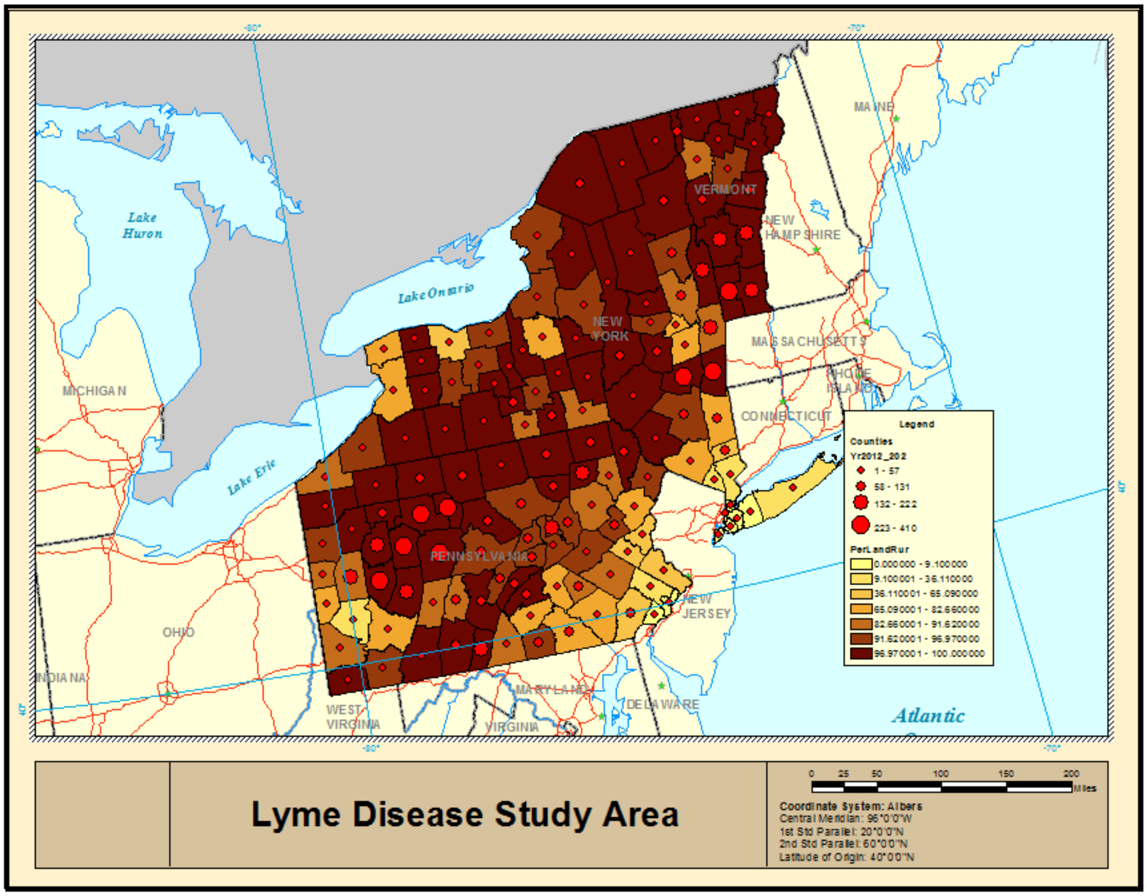


Figure 6 Urban Rural Codes from USDA from 2010

Figure 7 below Lyme disease cases in 2014 and their proximity to county recreational sites and watershed locations. These recreational sites provide opportunity and access were humans and ticks have potential interaction. The Hudson River is a major waterway for the Hudson River Valley and a source of outdoor water activities. There is a very clear pattern of recreational sites and sources of water near forested areas that correlate closely to higher incidence of Lyme cases. The recreational sites in lower Vermont and Northwestern Pennsylvania are in close proximity to counties that exhibit over 200+ cases annually. According to the Heinz Center, nearly half of all recreation activities occurs in forested areas of America. In 2013 alone nearly 160 million people visited US Forest Service lands for recreation opportunities and 86% described the forest as their primary destination (USDA, 2013).

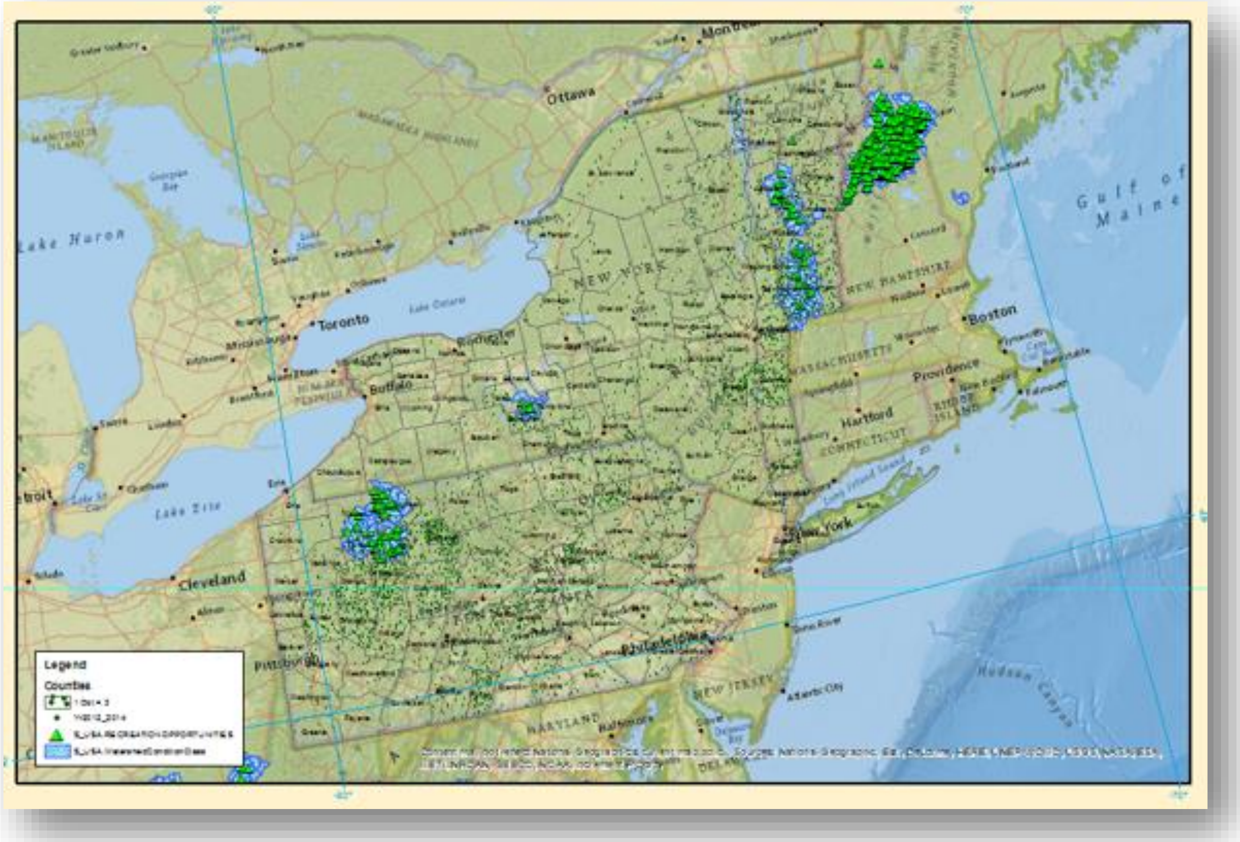


Figure 7 Recreation Sites and Major Watershed sites from US Forest Service

Soil and Slope

The maps that are part of Figure 8a below show the relation of soil with observed Lyme cases. The Lyme disease cases are shown for 2014 for the study area along with Lyme cases for each county. The 2014 soil maps show PH and types of soil associated with various regions within the study area. The data shows that soils associated with sandy loam and lower PH levels area counties exhibit a tendency for more Lyme cases and ticks. A study done in 2002 by Marta Guerra et al showed that acidic soils and clay soil textures were associated with tick absence while those with sandy loam and less acidic did not. Figure 8b shows on the right in green areas of higher acidic soil and lower Lyme incidences. The left shows various soil order and that sandy loam soils found in alfisols tended to be associated with higher incidence of Lyme disease and less acidic soils as shown in Figure 8b. Figure 9 below show how elevation slope is related to Lyme incidences. The less slope relates to areas more conducive higher contraction of Lyme disease.

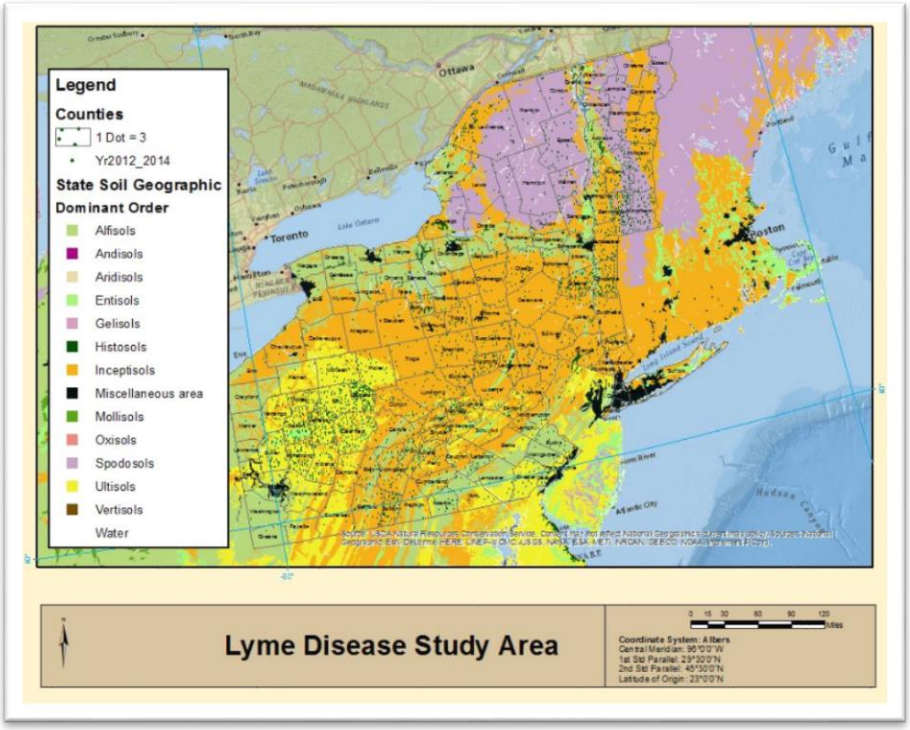


Figure 8a Soil Types and Lyme Cases for 2012-2014

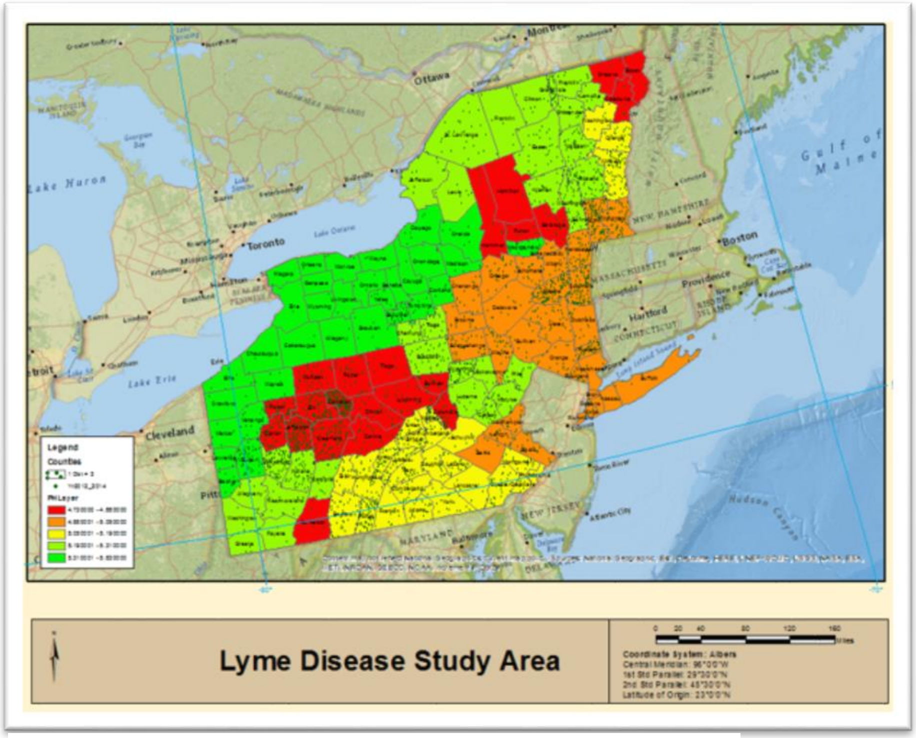


Figure 8b PH Soil Levels and Lyme Cases 2012-2014

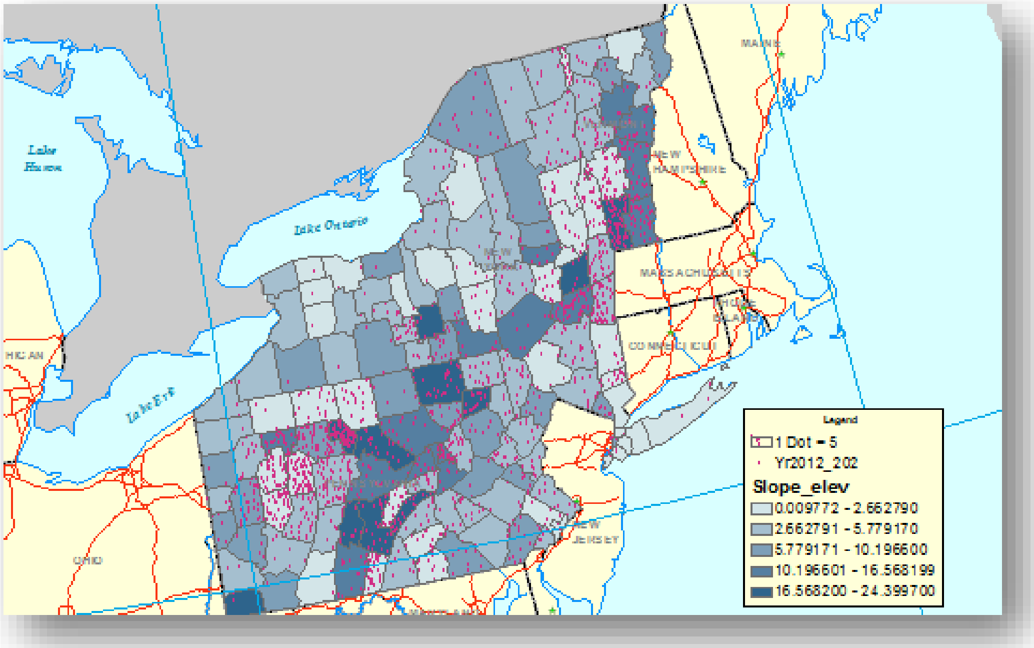


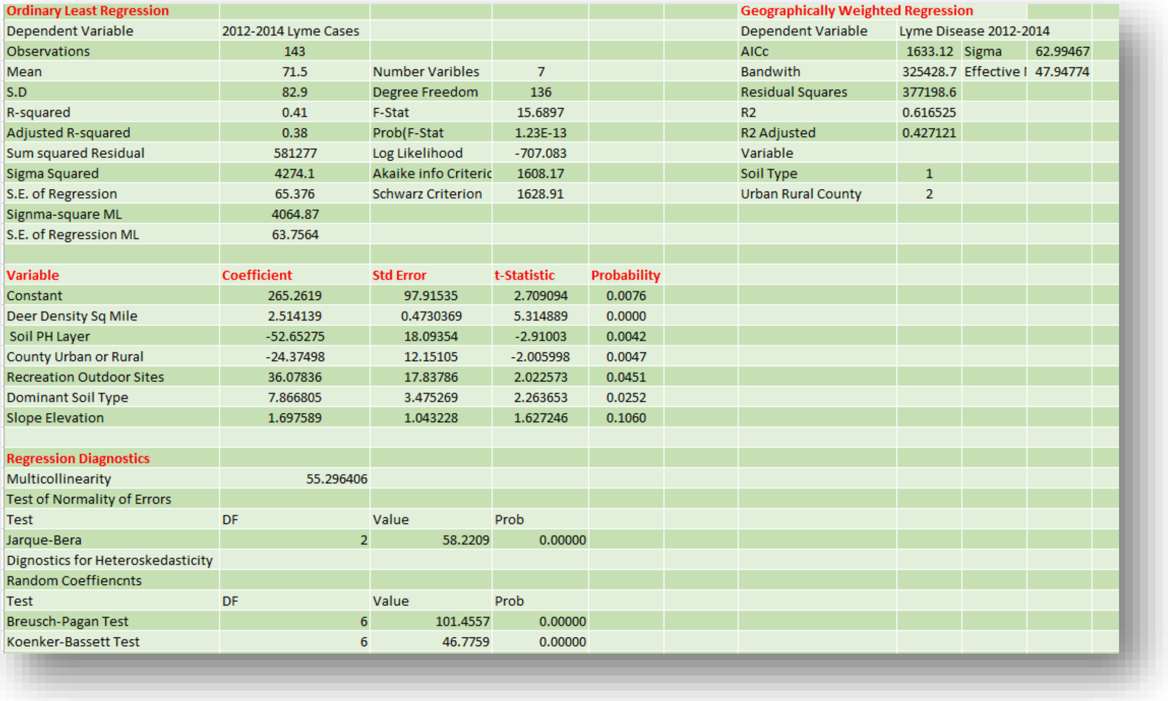
Figure 9 Slope Elevation showing low areas in light blue with higher Lyme Cases

Analysis

Regression analysis was done using the factors explored above. The results are shown in the Table 3 below using Ordinary Least Squares regression to check the model ability to predict the dependent variable Lyme incidences for years 2012-2014. Independent variables used as predictor values were deer density, soil PH, soil types, rural county indicator, and outdoor recreation opportunities. The adjusted R-squared for this model explains 47% variation in the cases of Lyme disease for these 3 states. The strongest positive relationships are variables for positive recreation opportunities, negative metro and less acidic soil are shown in Table 5 these reflect independent Regression Coefficients using OLS Regression Analysis OLS.

The Geographically Weighted Regression shows a R2 of 62% for these variables as shown in Table 4. The housing percentage change for units from 1990 to 2000 are shown in Figure 10 below. Although growth in housing numbers for rural neighboring counties of Lyme cases is shown, it did not materialize as a significant variable in this model. Overall the results reflects some growth in communities along the Hudson River and near Allegheny. Most housing unit changes in black are reflected in larger rural counties in close proximity to the New York and Philadelphia metro regions. This pattern should be monitored as it may signal future spread for rural housing or cross county movement of people getting Lyme after traveling to these areas. Figure 11 shows the potential that across the country more than 57 million acres could experience a substantial increase in housing densities shown by the darker patches of red. The Hudson River corridor and Allegheny Forests are clearly near this new concentration of future housing growth.

Table 3 OLS and GWR Regression Results for Lyme Incidences for 2012-2014



Ordinary Least Regression					Geographically Weighted Regression			
Dependent Variable	2012-2014 Lyme Cases				Dependent Variable	Lyme Disease 2012-2014		
Observations	143				AICc	1633.12	Sigma	62.99467
Mean	71.5	Number Varibles	7		Bandwith	325428.7	Effective I	47.94774
S.D	82.9	Degree Freedom	136		Residual Squares	377198.6		
R-squared	0.41	F-Stat	15.6897		R2	0.616525		
Adjusted R-squared	0.38	Prob(F-Stat	1.23E-13		R2 Adjusted	0.427121		
Sum squared Residual	581277	Log Likelihood	-707.083		Variable			
Sigma Squared	4274.1	Akaike info Criteric	1608.17		Soil Type	1		
S.E. of Regression	65.376	Schwarz Criterion	1628.91		Urban Rural County	2		
Signma-square ML	4064.87							
S.E. of Regression ML	63.7564							
Variable	Coefficient	Std Error	t-Statistic	Probability				
Constant	265.2619	97.91535	2.709094	0.0076				
Deer Density Sq Mile	2.514139	0.4730369	5.314889	0.0000				
Soil PH Layer	-52.65275	18.09354	-2.91003	0.0042				
County Urban or Rural	-24.37498	12.15105	-2.005998	0.0047				
Recreation Outdoor Sites	36.07836	17.83786	2.022573	0.0451				
Dominant Soil Type	7.866805	3.475269	2.263653	0.0252				
Slope Elevation	1.697589	1.043228	1.627246	0.1060				
Regression Diagnostics								
Multicollinearity	55.296406							
Test of Normality of Errors								
Test	DF	Value	Prob					
Jarque-Bera	2	58.2209	0.00000					
Dignostics for Heteroskedasticity								
Random Coeffiencnts								
Test	DF	Value	Prob					
Breusch-Pagan Test	6	101.4557	0.00000					
Koenker-Bassett Test	6	46.7759	0.00000					

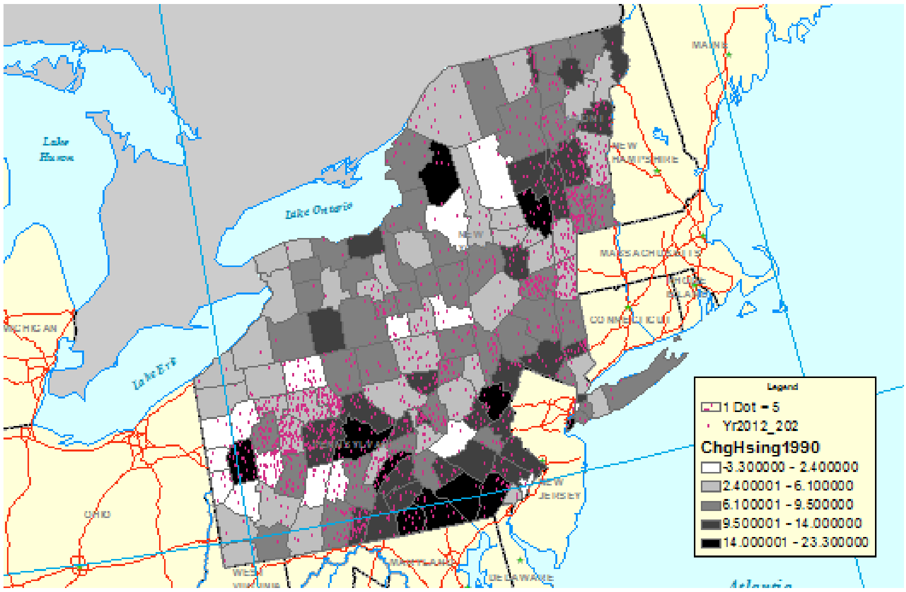


Figure 10 Percentage Change in Total Housing Units 1990-2000

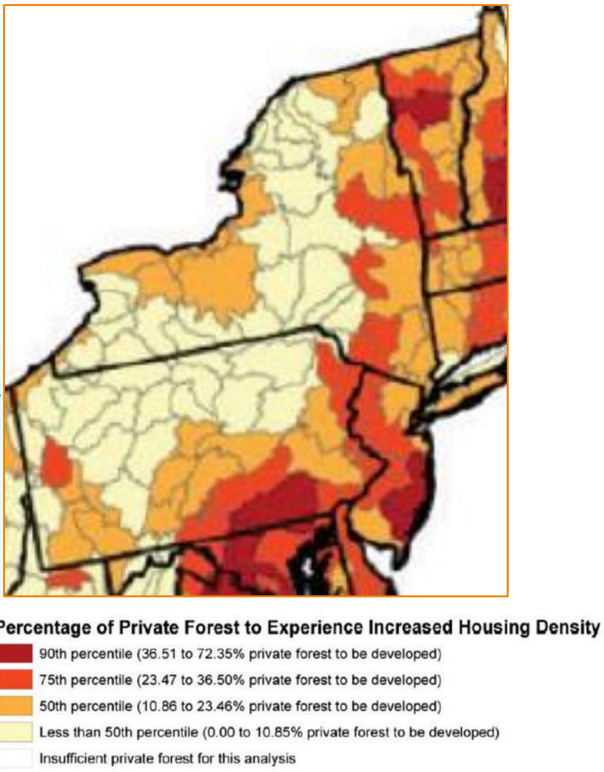
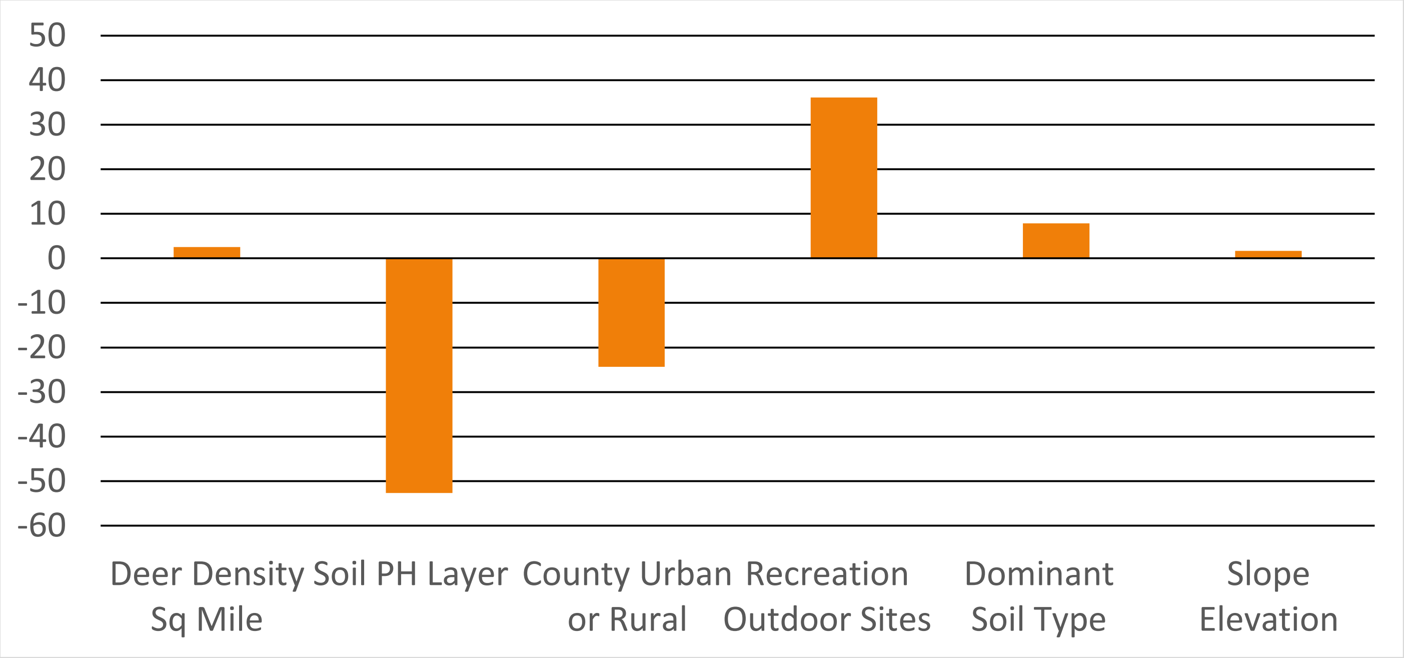


Figure 11 % of Private Forest increase Housing Density 2000 to 2030 by USFS

Table 4 Regression Analysis Coefficient and R2 Value of 41% showing Independent Variables



The results show that condition such as soil and certain forested rural habitats are needed for tick populations to thrive. It also showed that deer densities and location of outdoor recreation provide two methods for ticks to infect human hosts. The deer is the host that transports ticks and outdoor recreation within forest provide a haven of interaction

Conclusion

The data was first compiled and Lyme disease cases were examined for the period of 2012- 2014 for 143 counties in Pennsylvania, New York and Vermont. The states had various levels of Lyme disease incidences that categorized them as high-high in regards to risk and located in states that border each other successively. The goal of the study was to find factors that could determine the differences in exposure rates and glean if these variables could be utilized to create a predictive model for the spread of Lyme disease.

The raw numbers were divided by county populations and smoothed to do a comparative analysis. The geographic distribution was first examined to determine randomness or not. A spatial Moran I analysis of cases compiled by counties were checked for randomness late periods of 2012-2014. Lyme disease exhibited clustering and a positive spatial autocorrelation for this period.

A LISA cluster map was produced using GeoDa to closely look at significant counties that exhibited hot spots or cold spots to examine. The results were 25 low-low and 16 high-high counties at .05 significance level. The contributing factors to tick and Lyme disease were looked at in greater detail and examining these 20 counties. Environmental, soil, white-tailed deer and outdoor recreational factors were examined in greater detail.

Finally, a model was created that explained 41% of the results of Lyme disease cases for these counties. An important factor were ecoregions located near river basins and forest edges. Surprisingly, winter temperatures not being too low for the nymph deer tick to survive and forest canopy coverage did not show as significant variables. While not an independent variable, it may help to explain why 25 low statistical exist along Lake Erie. Lake effects tend to keep winter temperature too low for tick survival. The study showed river ecosystems do play a vital role in determining where deer ticks and Lyme disease cases can be found. The Hudson River and Allegheny River ecosystems are regions exhibiting high disease cases. The need for water and deer habitation along these river corridors correspond to these rural counties as well. The independent factor of Outdoor Recreational Activities did show a correlation as independent factor to Lyme cases. This does make sense that such activities as hunting, camping, and hiking places humans in risk and contact with ticks that carry the Lyme disease bacteria. Another issue that couldn't be discerned was the effects of urban sprawl on this problem. Population changes over past 4 years in the rural counties with higher Lyme rates exhibit no dramatic increases. However, within these rural counties housing densities have placed populations closer to forest edges and fragmented forest areas.

A vital outcome to using this data is to locate key risk areas and employ countermeasures and methods to help alleviate the burden of its health care costs. Risk areas need to implement signs to warn of Lyme disease and tick populations to people enjoying these sites. Applications on popular social media sites should contain Lyme disease risk zones to create awareness. The biggest need is provide medical funding to get a vaccination or treatment plan with use of antibiotics for this disease. A recent survey found only 2% of doctors treat Lyme disease and that over 50% surveyed didn't believe chronic infection even exits. The biggest hurdle is to clear this lack of awareness and to provide much needed research dollars toward this issue.

The trend of warmer winters and flooding from climate change only increases areas that will become potentially exposed to deer tick populations. The pattern in these states shows an increase toward more northern regions. The likelihood is deer populations are migrating to more rural northern areas as winter temperatures warm up. This will mean more cases of Lyme disease in areas never seen before. The warmer temperatures also increase tick populations as this warming trend speeds up the reproduction process (CDC, 2016). The results in the future will be larger tick populations across wider expanses of area as these new areas open up from the effects of global warming. This will only open up the opportunity for more widespread infections and lives being detrimentally altered by this disease.

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