Exploring Local Environmental Factors Influencing Geographic Distribution of Black-Legged Tick Questing Activity

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Abstract

The deer tick (*Ixodes scapularis* or *I. scapularis*), also known as the black-legged tick, is the primary vector that transmits Lyme Disease (LD) in Northeastern United States. To contain the geographic expansion of Lyme disease ticks across the US in recent decades, ecological studies have been conducted to understand the biotic and abiotic environmental factors affecting tick activity. We observed in preliminary surveys that the tick host-seeking activity varies across small local areas. The primary objective of this project is to identify the environmental factors that impact deer tick questing activities at the micro-geographic scale. From 2017-2018, we collected ticks at four New York City suburban locations during tick nymph and adult questing seasons. Tick sampling was conducted within 5m × 5m sites and field data including surface temperature and relative humidity were measured. Meanwhile, geospatial technologies were leveraged to process digital images including LIDAR (Light Detection and Ranging) and NAIP (National Agriculture Imagery Program) in order to acquire environmental data with high spatial resolution. Regression models were then built with respect to different temporal scales and evaluated with the AICc (Akaike Information Criterion) approach. Modeling results reveal that predictors including temperature and NDVI (Normalized Difference Vegetation Index) define the temporal patterns of the tick questing activity while hardwood coverage and forest boundaries define its spatial patterns. The finding suggests that suburban areas with more hardwood coverage as well as landscapes under more fragmented canopies may be characterized with higher questing tick populations.

Introduction

The black-legged tick (*Ixodes scapularis* or *I. scapularis*), also known as the deer tick, is the primary vector that transmits Lyme disease (also called Lyme Borreliosis) in North America. Since 2008, in the United States, over 30,000 Lyme disease cases are reported nationwide every year (most incidences of Lyme disease in the western United States are caused by another *Ixodid* tick species called the western black-legged tick, *I. pacificus*). (**Figure 1**)

Figure 1: An adult female black-legged tick questing for host. (Image from https://www.rosepestcontrol.com/)

Occurrence of the black-legged tick used to be prevalent and endemic to the central-northern, northeastern and eastern United States. Due to climate change, a considerable number of black-legged tick infested area have been observed in the southern and south eastern United States potential to increase Lyme disease risk in local area and pose serious threat to public health. (**Figure 2**)

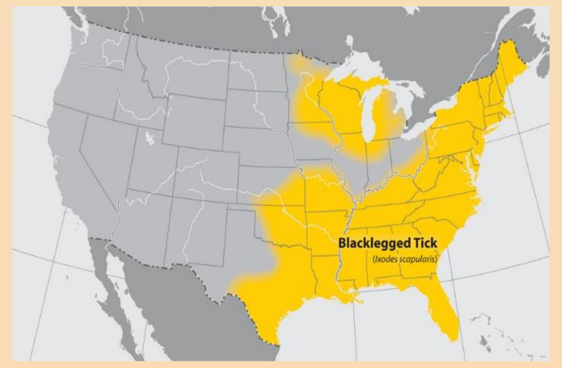

Figure 2: Expanding geographic distribution of black-legged tick habitat in the United States. (Image from https://www.cdc.gov/)

As a cold-blooded terrestrial species, the black-legged ticks spends over 90% of its life time (usually 2 years) off-host struggling with environmental stressors to survive. The spatial-temporal pattern of questing activity is highly regulated by a wide variety of environmental factors. Based on this, tick ecology is usually studied by analyzing a certain number of environmental variables.

Method & Materials

Tick Sampling

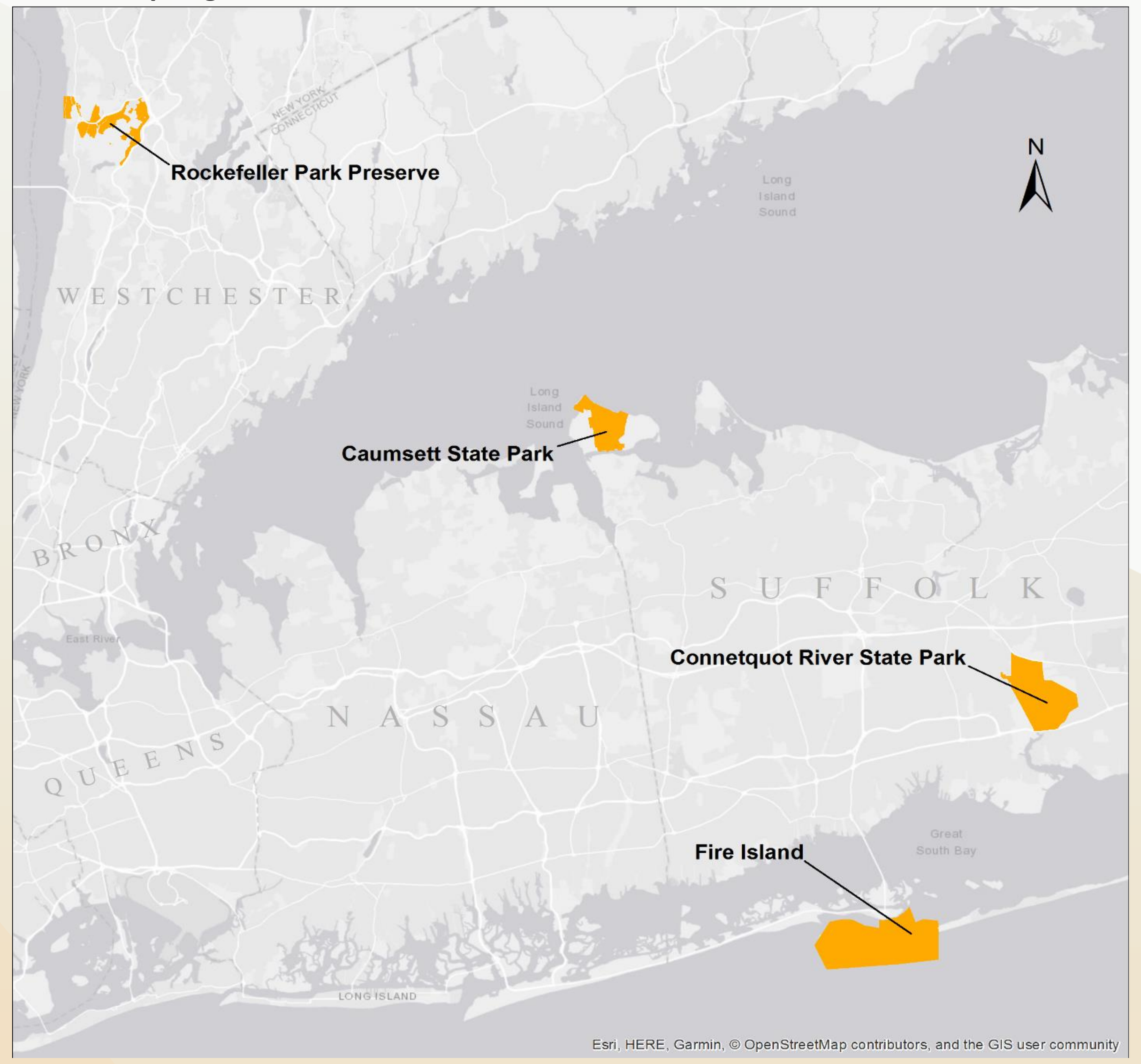

Figure 3.: Map of the Study Areas. Tick expeditions were conducted in *Caumsett State Park* (*CSP*), *Connetquot River State Park* (*CRSP*), *Rockefeller Park Preserve* (*RPP*), and *Fire Island National Seashore* (*FINS*).

Figure 4: (left) "Flagging" was conducted to 5m × 5m transects that were pre-selected and marked in the field. Tick numbers collected within the same transect were aggregated. Field data including geographic coordinates, surface temperature, and relative humidity were measured during field work; **(right)** a host-seeking adult female deer tick on the leaf tip.

LIDAR (Light Detection and Ranging) Data Processing

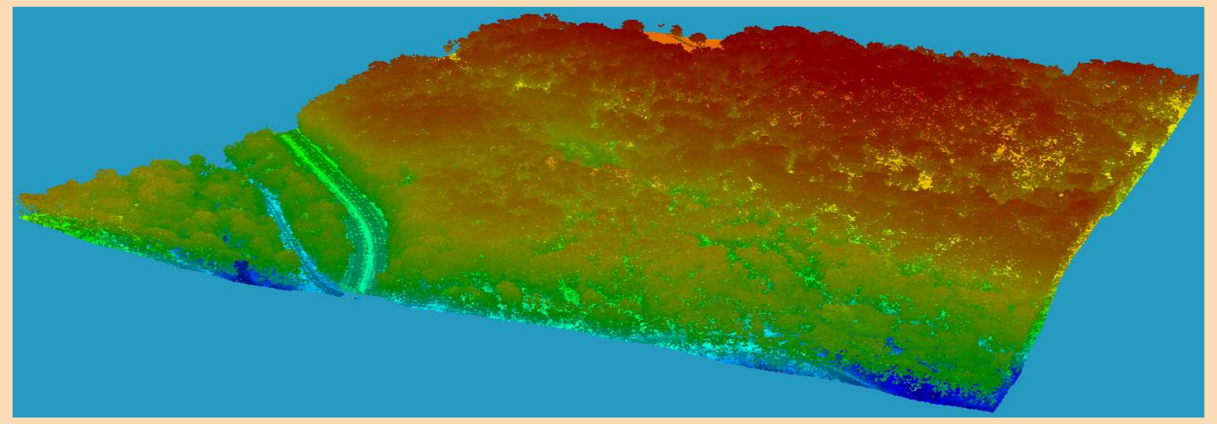

Figure 5: A sample LIDAR point cloud illustrates the landscape of *Rockefeller Park Preserve* with color indicating altitude values (points with warmer colors have higher altitude values whereas points with colder colors have lower altitude values). LIDAR data was loaded into SAGA GIS and processed at 1m spatial resolution.

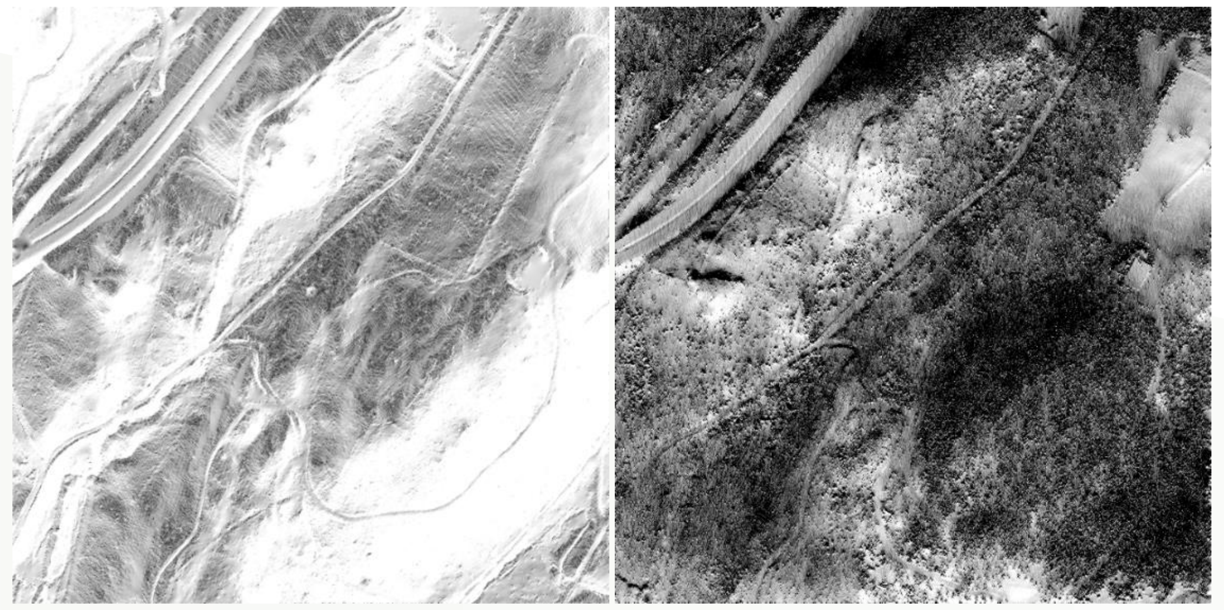

Figure 6: LIDAR data was used to produce raster images where the environmental data could be extracted based on the location of sampling transects. **(left)** Digital Terrain Model (DTM, presented with hillshading) was calculated only from ground points in order to obtain digital elevation of the study area; **(right)** producing potential solar radiation raster maps depends on a variety of input factors including sun hour, sampling date (which determines the sun zenith on specific sampling date), atmospheric transmissivity. Primary input for computing solar radiation is the digital surface model (DSM) which depicts characteristics of earth surface and could be calculated from LIDAR data. LIDAR processing was done by using SAGA GIS libraries.

NAIP (National Agriculture Imagery Program) Image Processing

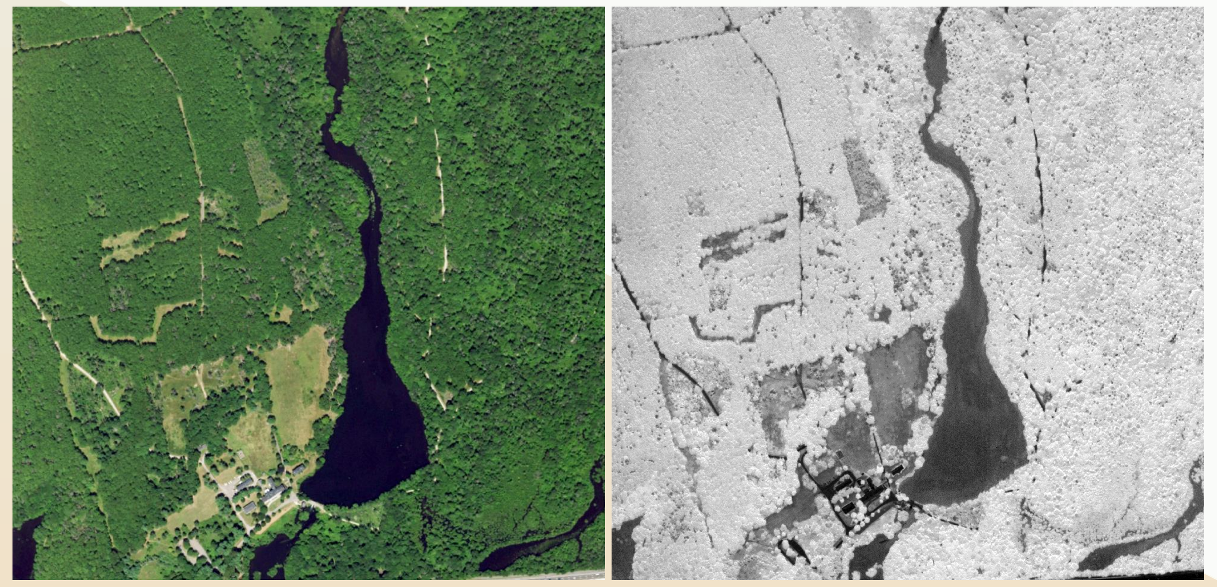

Figure 7: The first implementation of NAIP remote sensing images **(left)** is to compute normalized difference vegetation index (NDVI) using its red and near infrared channels based on the formula:

$$NDVI = \frac{Band_{near\ infrared} - Band_{red}}{Band_{near\ infrared} + Band_{red}}$$

NDVI value **(right)**, ranging from -1 to 1, is an indicator for the greenness of vegetation. Area with NDVI value ≤ 0 indicate non-vegetation and vice versa. Area with NDVI values close to 1 suggests dense and vigorously growing vegetation. Comparing with Landsat satellite imagery (30m spatial resolution), NAIP image is of 1m spatial resolution and therefore it is able to reveal a lot more detailed information under tree canopy. In this study, NDVI raster images were calculated using band algebra library in ArcGIS.

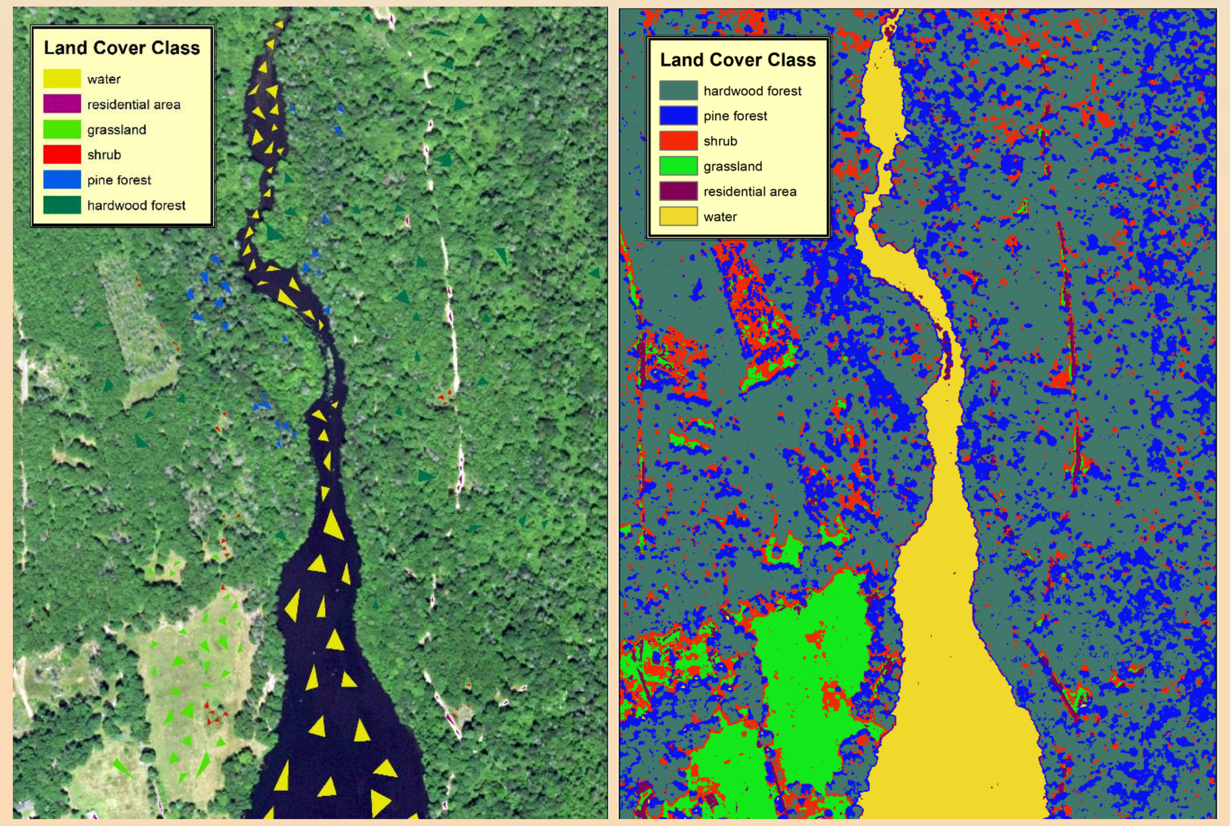

Figure 8: In addition to calculating NDVI values, the second implementation of NAIP image was the land cover classification. Due to the high spatial resolution of NAIP imagery, it is simple for users to visually identify land cover from the image. (**left**) Over 50 polygons were created manually as training dataset on the NAIP image for each pre-identified land cover class respectively. (**right**) Selecting training dataset, land cover classification and accuracy assessment were performed multiple times in ArcGIS in order to optimize outputs. (Overall accuracy of land cover classification: Caumsett State Park = 89.88%, Connetquot River State Park = 92.79%, Rockfeller Park Preserve = 97.08%, Fire Island Nation Seashore = 85.71%.)

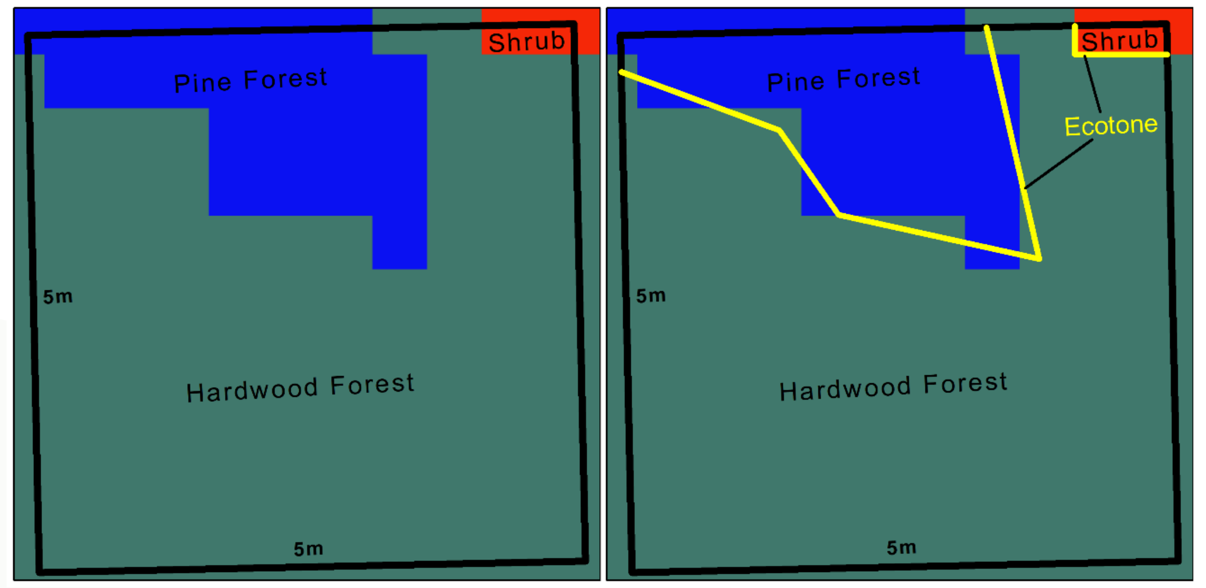

Figure 9: With the classified map, coverage with respect to land cover class were summarized by aggregating corresponding raster cells within each transect. In addition, the classified map also was used to compute the length of ecotone (addresses the boundaries between two different biological communities). **(left)** first step was to overlay a polygon (with 5m × 5m squares representing sampling transects) feature layer to the classified map (raster layer); **(right)** the polylines within transects were used to approximate the forest boundaries, also known as the ecotones.

Results

Tick Survey

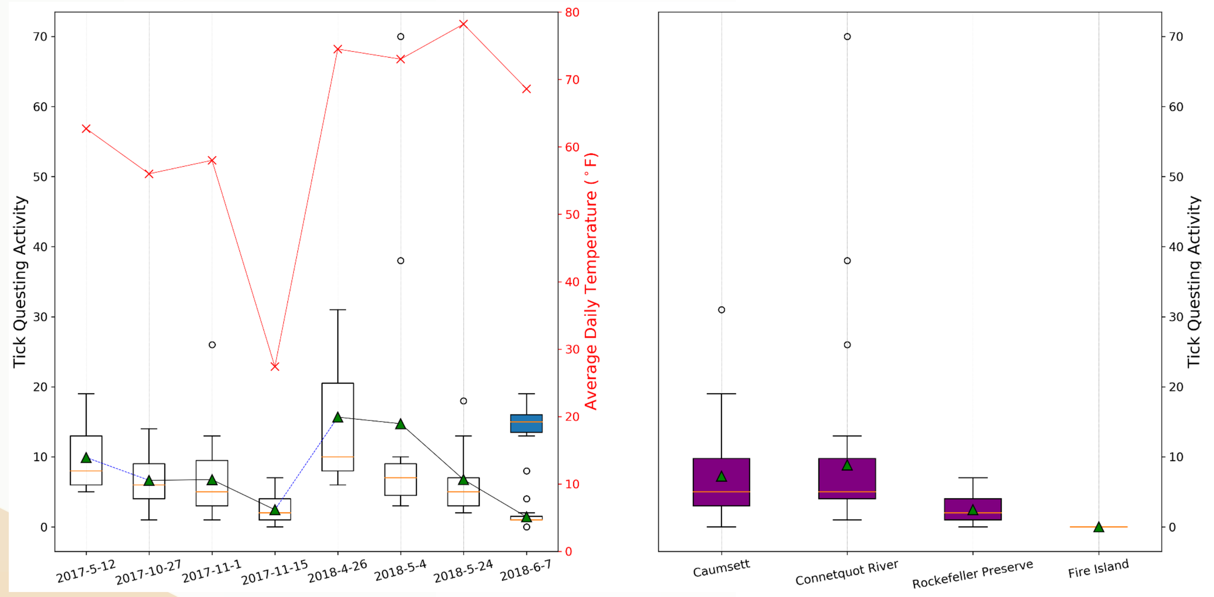

Figure 10: (left) Numbers of questing ticks (adult deer ticks are represented with white boxes; nymphal deer ticks are represented with blue boxes; mean tick numbers are represented with green triangles; red line indicates average daily temperatures; blue lines indicate seasonal gaps, during which ticks remain inactive because of the developmental diapause) are summarized by sampling date. Adult tick population is annually bimodal: tick activities generally peak in mid spring and mid fall (during which climatic variables and tick activities are consistent, *t* = 0.684, *p* = 0.496) but significantly decrease at the end of the seasons (*t* = -4.253, *p* = 4.375 × 10^{-5}, comparing with peak seasons); **(right)** Questing tick population summarized by sampling area. *Caumsett State Park* (*CSP*) and *Connetquot River State Park* (*CRSP*) in Long Island, NY are geographically close, tick numbers observed in these two parks don't appear to be significantly different (*t* = -0.586, *p* = 0.562). However, sampling results in *Rockefeller Park Preserve* (*RPP*) and *Fire Island National Seashore* (*FINS*) are inconsistent with the previous two parks. The reason may be that RPP locates in the Westchester County and its elevations are generally higher than parks in Long Island; in addition, FINS is characterized with desert-like landscape, making the local woodland habitats unable to maintain sufficient air moisture for a large deer tick population (only 4 deer tick nymphs were collected during a four-hour tick expedition).

Regression Analysis

Model		Equation	Parameter		
			p-value	r^2	adj-r^2
S_1	$M_{1.1}$	*y = -9.974 + 12.508 × season*** + 27.798 × ndvi** - 11.611 × pine*	0.0013	0.1862	0.1541
	$M_{1.2}$	*y = -16.516 + 0.223 × temp*** + 17.829 × ndvi + 5.789 × hardwood*	0.0035	0.1626	0.1295
	$M_{1.3}$	*y = 5.875 (null model)*	-	-	-
	$M_{1.4}$	*y = -21.049 + 20.571× season** + 0.133 × elv + 25.966 × ndvi***	0.0014	0.1847	0.1526
	$M_{1.5}$	*y = -11.095 + 0.204 × temp*** + 18.700 × ndvi**	0.0033	0.1373	0.1149
S_2	$M_{2.1}$	~~*y = -14.534 + 22.483 × hardwood* + 0.439 × ecotone**~~	~~0.0377~~	~~0.1478~~	~~0.1062~~
	$M_{2.2}$	*y = -14.534 + 22.483 × hardwood* + 0.439 × ecotone**	0.0377	0.1478	0.1062
	$M_{2.3}$	*y = 3.254 + 21.235 × ndvi*	0.0869	0.0682	0.0460

Table 1: Regression models were constructed with respect to different temporal scales because tick population (abundance) and activity are subject to seasonal changes. In addition, predictor variables were reduced in each candidate model using a stepwise algorithm based on their AIC values. In first scenario (***S_1***) where models were built involving the transects surveyed across all seasons, tick numbers appear to have significant correlation with season, surface temperature, and normalized difference vegetation index, the variables that may significantly vary across seasons. Additionally, model coefficients reveal that it may be more likely to observe higher questing tick population in the areas with warmer surface temperature and higher NDVI values. In stark contrast, second scenario (***S_2***) only took into account the transects surveyed within single season, during which seasonal variables are usually consistent. As a result, model ***$M_{2.2}$*** ignoring seasonal variables suggests that there is positive correlation between deer tick activity and local hardwood coverage, as well as ecotonal length.

Conclusion

Overall, dominant local environmental predictors vary with respect to illustrating the spatial and temporal patterns of deer tick questing activity. The temporal pattern of ticks' host-seeking activity is regulated by seasonality, which is consistent with temperature and vegetation index and also serves as an indicator for tick life stages. In general, habitats characterized with warmer surface temperature and more vigorously growing plant coverage tend to have higher questing deer tick populations. Conversely, significant decrease in questing tick populations may occur when environmental variables fall outside suitable intervals for tick activity. On the other hand, the spatial pattern of tick questing activity is defined by local landscape of vegetated area. Hardwood forests characterized with large canopy layers formed by round-leafed deciduous tree species, as opposed to needle-leafed pine forests where the microclimate is usually hotter and dryer[1], are better at maintaining air moisture in a way that is more beneficial to deer tick habitats. In addition, spatially more heterogeneous suburban landscapes with fragmented tree canopies seem to have larger questing deer tick populations[2] since these areas are covered by abundant ecotonal vegetation that provide preferred forage to support large population and diversity of the tick's host species[3,4].

Reference

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USGS Earth Explorer: LIDAR and NAIP remote sensing images (https://earthexplorer.usgs.gov/)

Centers for Disease Control and Prevention (CDC): Reports from Lyme Disease Surveillance (https://www.cdc.gov/)