ASSESSING THE KNOWLEDGE, ATTITUDES, PRACTICES, AND THE RISK OF TICK EXPOSURE OF PARK VISITORS ON STATEN ISLAND, NEW YORK

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ABSTRACT

Parks are important for human health, but they may expose visitors to ticks and tick-borne diseases. I sought to understand tick exposure risk and drivers of tick-preventative behavior in three parks on Staten Island, NY from May to August 2019.

Nymphal density was highest between early June to early July, in Conference House Park, unmaintained herbaceous habitats, and trails. The fewest people visited Conference House. Men and adults visited hazardous areas most frequently, but seniors disproportionately visited hazardous areas compared to other age groups. Overall, 190 visitors were interviewed, and most could not identify a nymphal tick. Interviewees stated that parks were the main location for tick exposure (43%), but most believed they had minimal risk for tick encounter (43%). Consequently, many individuals do not conduct tick checks (42%). Drivers of practicing tick checks were knowing multiple prevention methods and tick habitats and perceiving a high likelihood of tick encounter.

In dedication to and in memory of James Stewart:

my dear friend and inspiration who began this journey with me

but who cannot be there at the end.

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CHAPTER 1

LITERATURE REVIEW

The Growing Public Health Importance of Tick-borne Diseases

Tick-borne diseases (TBD) are a major public health concern in the United States as the distribution of medically important tick species continues to expand (Ogden et al. 2009, Nelson et al. 2015). Total TBD cases have increased from 22,527 in 2004 to 59,349 cases in 2017 (Centers for Disease Control and Prevention 2019a). Lyme disease is the most prevalent vector-borne disease in the United States with 20,000 to 30,000 reported cases every year for the past decade. However, this is likely underreported and actual prevalence is closer to 300,000 annual cases, concentrated mainly in the New England, Mid-Atlantic, and Upper Midwest regions (Centers for Disease Control and Prevention 2019b, 2019c). The number of counties reporting presence of the Lyme disease-causing bacterium vector, *Ixodes scapularis*, has more than doubled in the United States over the previous 20 years (Centers for Disease Control and Prevention 2019d). Meanwhile, the vector for pathogens causing ehrlichiosis and tularemia, *Amblyomma americanum*, is expanding from its southeastern territory to more northern and midwestern states (Centers for Disease Control and Prevention 2019d). New tick-borne pathogens have emerged in the past two decades such as *Borrelia mayonii, Borrelia miyamotoi, Ehrlichia ewingii, Ehrlichia muris eauclairensis,* Heartland virus, *Rickettsia parkeri,* and *Rickettsia species 364D*, now totaling sixteen TBDs in the United States (Centers for Disease Control and Prevention 2019d, 2019e). Furthermore, the newly invasive *Haemaphysalis longicornis* is a potential threat in the northeast United States since it transmits human pathogens in its native range (Rainey et al. 2018, Centers for Disease Control and Prevention 2019d).

Currently, there are five major tick species in some or all regions of New York State (NYS) that have the potential to spread disease to humans: *I. scapularis* (blacklegged or deer tick), *A. americanum* (lone star tick), *Dermacentor variabilis* (American dog tick), *Rhipicephalus sanguineus* (brown dog tick), and *H. longicornis* (Asian longhorned tick). The biology and ecology of these species are important for understanding transmission potential and risk. My research focused on three species found on Staten Island, NYS: *A. americanum, I. scapularis,* and *H. longicornis.*

Three-Host Ixodids (*Ixodida: Ixodidae*)

There are important characteristics of family Ixodidae (the hard ticks) that affect their ability to transmit disease. First, ixodids have a relatively extensive hemimetabolous life cycle lasting two to six years consisting of a six-legged larva, an eight-legged nymph, and an adult (Anderson and Magnarelli 2008, Sonenshine and Roe 2014). Second, three-host tick species have one host per life stage, and a blood meal is required for molting and egg production. Mating may occur before or during a blood meal (Sonenshine and Roe 2014). With each successive host comes the opportunity of receiving and/or transmitting an infected blood meal. Third, hard ticks can withstand long periods of starvation by lowering their metabolism and slowly digesting their blood meal. This prolongs pathogen survival and protects the pathogen from being rapidly destroyed in the midgut (Sonenshine and Roe 2014). Fourth, the slow feeding during a blood meal allows pathogens adequate time to be transmitted. Subsequently, long attachment times on mobile hosts allow for individual dispersal across habitats and potentially into new habitats (Anderson and Magnarelli 2008).

Ixodes scapularis

I. scapularis (the blacklegged tick or deer tick) is a three-host, non-nidicolous hard-bodied tick that favors deciduous forest environments with shrub and moist leaf litter environments (Lubelczyk et al. 2004, Eisen et al. 2016). It has established populations in the Northeast, upper Midwest, and other areas across the eastern half of the United States (Centers for Disease Control and Prevention n.d.). Reforestation and the growth of the white-tailed deer population, a key host for *I. scapularis* (Lane and Burgdoifer 1991), may contribute to the species' expansion, in addition to environmental changes. From 1996 to 2015, the number of counties that reported *I. scapularis* doubled, and 1,531 (45.7%) of the continental United States counties reported this species (Eisen et al. 2016). An updated literature review is required to assess the current county-level distribution.

I. scapularis is a generalist feeder with a two-year life cycle. Under certain conditions in northeastern North America where the larvae may not feed until the summer after hatching, it can survive for three to four-years (Yuval and Spielman 1990). Mating occurs both on or off-host, and the female adults lay eggs in batches of 1000 to 2000 (Anderson and Magnarelli 2008) during the same time of year. In New York, eggs are laid in mid- to late-May, regardless of what season feeding took place (Daniels et al. 1996). The larvae hatch in the summer and enter winter diapause. Afterwards, they take their first blood-meal in the spring before molting into nymphs. Nymphs take a blood-meal and molt into adults by the fall. After the second winter diapause, adults lay eggs in the spring and die (Ostfeld et al. 1995, Eisen and Eisen 2018).

Tick density is associated with moist forested areas that support vegetation for mammal hosts. In Westchester County, NY, tick density was greater in wooded areas with high levels of vegetation and moisture compared to lower moisture lawns (Dister et al. 1997). In Ontario, Canada, the presence of *I. scapularis* was positively correlated with the presence of dense understory, shrub abundance, and the interaction of shrubs and understory, likely due to small mammal hosts that may reside in shrub habitats (Clow et al. 2017). Similarly, On Fire Island, NY, nymphs were most abundant in woods, specifically in leaf litter, compared to grass-shrub habitats. This is because nymphal ticks quest on shorter vegetation where smaller mammal hosts are present, such as white-footed mice. Alternatively, *I. scapularis* adults were more prevalent in taller shrubs compared to woods, likely because adults host-seek for larger mammals (such as white-tailed deer) on taller vegetation. However, in the autumn, adults could be found in both taller shrubs and in woods (Ginsberg and Ewing 1989a).

Because *I. scapularis* density increases with proximity to forested areas, edges between woods and lawns (ecotone edges) are risky areas for human exposure to ticks and pathogens. In Armonk, NY, nymph and adult ticks (n=637) were the most abundant in woods (67.3%), followed by unmaintained (ecotone) edges (21.6%), ornamental areas (9.1%), and lawns (2%). Sixty-six percent of lawns (n=10) that had nymphs were adjacent to forested areas, indicating that suburban areas could be at risk for tick exposure if in close proximity to forests. Approximately 30% of all tested nymphs were infected with *B. burgdorferi* (n=94/317), and infected nymphs were found in all habitats, including lawns. As lawn size increased, tick abundance increased (Maupin et al. 1991). Comparatively, Duffy et al. (1994) found that lawn size did not influence tick abundance on Shelter Island, NY, but woodlands also had the greatest number of ticks compared to yards, grasslands, beaches, salt marshes, and mesic areas (vegetation within 2 m of permanent or seasonal standing water). There was no difference in tick abundance between edges and woodlands, suggesting that ecotone edges were also a high-risk area for tick encounter. The abundance of *I. scapularis* in woods and edges translates into elevated abundance of *I. scapularis* in yards (Duffy et al. 1994). Likewise, Horobik et al. (2006) demonstrated that, in Duchess County, NY, nymphal *I. scapularis* density was highest within a forest, followed by ecotone edges, and was lowest within herbaceous fields. Consequently, Lyme disease incidence may be greater along ecotone edges where human contact and density of infected nymphs is high (Horobik et al. 2006).

The questing activity of *I. scapularis* differs by region and life stage. In the southeast, where *I. scapularis* is present, few questing nymphs have been collected in the field, and nymphal bites on humans are rare (Goddard and Piesman 2006, Stromdahl and Hickling 2012). This is possibly due to the presence of lizards, a viable host for questing nymphs at the surface level (Goddard and Piesman 2006). However, *I. scapularis* frequently quests and bites humans in the Northeast and upper Midwest (Stromdahl and Hickling 2012). The biological discrepancy between northern and southern *I. scapularis* may be due to the presence of two subspecies. Spielman et al. (1979) suggested the presence of two different species along the East Coast of North America with *I. scapularis* in the south and *I. dammini* in the north, based on morphological differences. The lack of a reproductive barrier and genetic variation between the two resulted in the synonym (Oliver et al. 1993, Wesson et al. 1993). Article 23 of the International Code of Zoological Nomenclature gave the senior naming priority to *I. scapularis* (Ride et al. 2000).

Tick density is influenced by host availability, and association varies by life stage. Larvae and nymphs often quest closer to the ground and feed on smaller mammals such as the white-footed mouse. As an adult, the tick will quest higher on taller vegetation, and white-tailed deer become the primary host maintaining the tick population (Wood and Lafferty 2013, Eisen and Eisen 2018). In New York, *I. scapularis* was present in or near residential yards, which coincided with the presence of white-footed mice, signifying that these ticks can host-seek in maintained lawns that have *B. burgdorferi* reservoirs (Falco and Fish 1988). *I. scapularis* will also feed on other mammals like shrews, opossums, and chipmunks (Hamer et al. 2012).

Questing activity also changes temporally by life stage as adults are more abundant in late fall and spring, nymphs in early summer, and larvae in late summer/early fall. Peak questing periods for the different life stages are shown in Table 1 for each state in the Northeast; however, more phenology data need to be reported in some northeastern states.

Table 1. *I. scapularis* questing periods in the Northeast United States.

State	Peak Questing Periods	Source
Connecticut	Nymphs: early June	(Feldman et al. 2015)
Maine	Larvae: Late July to late August Nymphs: mid-June to early July Adults: mid-October to mid-November; early May	(Lubelczyk et al. 2004, Diuk-Wasser et al. 2006, Rand et al. 2007)
Massachusetts	Larvae: August Nymphs: May to July Adults: March to May; October to November	(Xu et al. 2016, Ogden et al. 2018)
New Hampshire	Nymphs: mid-May to mid-July Adults: early October to mid-November; late March to May	(Eaton 2016)
New Jersey	Larvae: August and September Nymphs: May to July Adults: late October to early December; April to early May	(Schulze et al. 1986)
New York	Larvae: August to early September Nymphs: late June to early July Adults: Mid to late November	(Daniels et al. 2000)
Pennsylvania	Larvae: July and August Nymphs: May to July; Adults: November and April	(Han et al. 2014, Simmons et al. 2015)
Rhode Island	Larvae: mid-July to late August	(Huang et al. 2019)
Vermont	Larvae: August Nymphs: June to July Adults: March to May; September to December	(Serra et al. 2013)

I. scapularis is capable of transmitting seven known bacterial, viral, and protozoan pathogens to humans (Table 2). *Anaplasma phagocytophilum* (the causative agent of anaplasmosis), *Babesia microti* (babesiosis), *Borrelia miyamotoi* (tick-borne relapsing fever), *Borrelia mayonii* (borrelia mayonii disease), *Ehrlichia spp.* (ehrlichiosis), *Borrelia burgdorferi* (Lyme disease), and Powassan virus lineage II (deer tick virus disease) (Telford et al. 1997, Eisen and Eisen 2018).

Table 2. Human diseases caused by *I. scapularis*-transmitted pathogens.

Disease	Pathogen Species	Group	Citations
Anaplasmosis	*Anaplasma phagocytophilum*	Bacterium	(Aliota et al. 2014, Tokarz et al. 2017, 2019)
Babesiosis	*Babesia microti*	Protozoa	(Aliota et al. 2014, Tokarz et al. 2017, 2019)
Borrelia miyamotoi disease	*Borrelia miyamotoi*	Bacterium	(Tokarz et al. 2017, 2019)
Borrelia mayonii disease	*Borrelia mayonii*	Bacterium	(Dolan et al. 2016, Johnson, Graham, Hojgaard, et al. 2017)
Ehrlichiosis	*Ehrlichia spp.*	Bacterium	(Des Vignes et al. 2001, Aliota et al. 2014)
Lyme disease	*Borrelia burgdorferi*	Bacterium	(Aliota et al. 2014, Tokarz et al. 2017, 2019)
Powassan encephalitis	Powassan virus lineage II: deer tick virus	Virus	(Aliota et al. 2014, Tokarz et al. 2017, 2019)

Pathogen acquisition mainly occurs during blood ingestion when the tick feeds on an infected host. In some instances, cofeeding infections can occur when an uninfected tick feeds in close proximity to an infected tick (Patrican 1997). The infection occurs without a host systemic infection such as pathogen transportation throughout the lymphatic system (viruses) or self-mobility (*Borrelia spp.*) (Randolph et al. 1996). Coinfection can occur if a host is bitten by a tick carrying multiple pathogens or is bitten by multiple ticks carrying one or more pathogens (Eisen and Eisen 2018). It has also been shown that Powassan virus and *B. miyamotoi* can be transmitted vertically through transovarial transmission via infected ovaries (Costero and Grayson 1996, Han et al. 2019). Importantly, while white-tailed deer are crucial hosts for *I. scapularis*, they are incompetent for *B. burgdorferi* (Telford et al. 1988), so they cannot transmit *B. burgdorferi* to other feeding ticks.

In NYS, *I. scapularis* transmits *B. burgdorferi*, deer tick virus, *Babesia microti,* and *A. phagocytophilum* to humans (White n.d., Barbot 2019). In 2018, 53% (n=17846) of all Lyme disease cases in the US were in the Mid-Atlantic region, of which NYS reported 23% (n=5155) of the Mid-Atlantic cases (Centers for Disease Control and Prevention 2018). In 2018, *A. phagocytophilum* case rates were highest in the Northeast and Upper Midwest, with NYS reporting 46.9 cases per million people (Centers for Disease Control and Prevention 2020). From 2009 to 2018, there have been 24 Powassan virus (lineage II, deer tick virus) cases in NYS, with six in 2017 and four in 2018 (Centers for Disease Control and Prevention 2019f). While data from the CDC is unavailable for 2018 and 2019, the NYS Department of Health reported 696 cases of *B. microti* in 2017 (Gray et al. 2019).

The prevalence of pathogens in NYS *I. scapularis* populations varies by pathogen species. From 2015 to 2016, 115 *I. scapularis* nymphs in Suffolk County were tested with 7% were positive for *A. phagocytophilum* (n=8), 21% for *B. burgdorferi* (n=24), 7% for *Babesia microti* (n=19), and 3% for *B. miyamotoi* (n=4). Adults (n=89) were also infected with *A. phagocytophilum* (n=10; 11%), *B. burgdorferi* (n=60; 67%), *Babesia microti* (n=27; 30%), *B.*

miyamotoi (n=3;3%), and deer tick virus (n=2; 2%) (Tokarz et al. 2017). In a combined sample of nymphal and adult ticks from NY and Connecticut from 2016 to 2017, ticks were positive for *A. phagocytophilum* (n=21;10.6%), *B. burgdorferi* (n=111;56.3%)*, B. miyamotoi* (n=10; 5.07%), *B. microti* (n=17; 8.6%)*,* and Powassan virus (n=7; 3.6%) (Tokarz et al. 2019). From 2003 to 2006, nymphs (n=3300) and adults (n=7904) were tested in the Hudson Valley region, NYS. The presence of *B. burgdorferi, A. phagocytophilum,* and *Babesia microti* was 14.4, 6.5, and 2.7% in nymphs while adult infection was 45.7, 12.3, and 2.5%, respectively (Prusinski et al. 2014). Comparatively, the NYS Department of Health found that ticks (presumably adults and nymphs combined) in the Hudson Valley region were infected with *B. burgdorferi, A. phagocytophilum,* and *Babesia microti* (40-50, 7-15, and 1-3%, respectively) (Barbot 2019).

New York City (NYC), NYS, comprises five boroughs: Bronx, Brooklyn, Manhattan, Queens, and Staten Island, and *I. scapularis* is both abundant in the Bronx (northeast NYC) and widely established on Staten Island (southwestern NYC) (Barbot 2019). In 2019, ticks within nine parks on Staten Island and one park in the Bronx were tested for *B. burgdorferi*, and the total nymphal infection prevalence was 26% (n=149) (VanAcker et al. 2019). Supplemental data from the NYC Department of Health and Mental Hygiene showed that 47% of ticks (presumably adults and nymphs) tested positive for *B. burgdorferi* in the Bronx, and 20% were positive in Staten Island (Barbot 2019). Ticks on Staten Island also tested positive for *A. phagocytophilum* (0.06-10%)*, Babesia microti* (0-6%), and *B. miyamotoi* (2%). In 2016, one tick tested positive for deer tick virus, and in 2017, two ticks were positive in the Bronx (Bassett 2017, Barbot 2019).

Nymphs have the greatest role in *B. burgdorferi* transmission. Human exposure to *I. scapularis* nymphs in the summer comprises most of the Lyme disease cases in the US, likely due to the increased activity outdoors during the nymphal questing period and the small, often undetectable size of the nymphs (Mather et al. 1996, Stafford et al. 2017). In New Jersey from 2006 to 2016, the number of infected nymphs was significantly correlated with the number of Lyme disease cases (Jordan and Egizi 2019), highlighting the importance of nymph exposure risk. Measures such as density of nymphs per square area (DON), can help estimate tick contact risk while nymphal infection prevalence (NIP) assesses pathogen frequency. Multiplying the DON and NIP can provide a useful metric of the density of infected nymphs per square area (DIN) (Johnson, Graham, Boegler, et al. 2017, VanAcker et al. 2019). Because the prevalence of locally-acquired Lyme disease is affected spatially and temporally by the density of *B. burgdorferi* infected ticks and human exposure to those ticks (Chen et al. 2005), it is necessary to decrease both tick abundance and human exposure risks.

To conduct tick and pathogen surveillance, efficient sampling methods for the target tick species is essential. Common methods for collecting *I. scapularis* include dragging or flagging a white cloth along vegetation and checking for ticks at fixed distances, deploying CO_2-baited traps to mimic hosts, walking collections, and mammal trapping (Ginsberg and Ewing 1989b, Schulze et al. 1997). When collecting ticks via dragging, frequent check distances along a fixed transect aid in minimizing tick drop-off. In Vermont, adult ticks tended to drop-off the drag cloth more frequently than nymphs (0.083 adults/m; 0.047 nymphs/m), and the further the check distance, the more likely ticks would drop-off (Borgmann-Winter and Allen 2019).

Amblyomma americanum

A. americanum (the lone star tick) is a three-host, aggressive tick species with generalist feeding tendencies (Childs and Paddock 2003, Goddard and Piesman 2006) and a life cycle that can last up to two years under laboratory conditions (Troughton and Levin 2007). It is considered both a human and agricultural pest (Hair 1970). The preferred habitat of this species comprises woodlands and dense underbrush that support white-tailed deer populations (Kollars 1993, Paddock and Yabsley 2007). Even though it is predominately a southern tick, its current distribution is now from Florida to southern Maine and as west as central Texas and eastern Nebraska (Centers for Disease Control and Prevention 2011). This tick has also established populations in NY (Ginsberg et al. 1991), and models suggest favorable climate in California and the potential for this tick to expand into the upper Midwest (Raghavan et al. 2019).

The phenology of *A. americanum* is similar to *I. scapularis*, but data are lacking for most states in the Northeast US. In Connecticut, adults were active from March to mid-April, and nymphs appeared in mid-May, with peak activity from June to July. Larvae appeared in late summer to early fall (Stafford 2007). Passive submissions from 2006-2016 in New Jersey showed that peak activity for nymphs was in June, while adult submissions were low from April to August with a mild peak between June and July (Jordan and Egizi 2019). Adult and nymph density on mammals in New Jersey was highest in June and July, and larvae density was highest in early May and mid-September (Schulze et al. 1986), showing that seasonality and life stage affect questing behavior.

Abiotic conditions influence tick density and survival. *A. americanum* was found to survive longer in oak-hickory habitats compared to open meadows in eastern Oklahoma, presumably due to the more favorable lower temperatures and higher humidity (Patrick and Hair 1979). Gravid females also opted for lower temperature habitats for oviposition, and mortality for female adults was observed in the open meadow habitat (Patrick and Hair 1979). Conversely, in New Jersey, *A. americanum* was collected more frequently during diel periods of higher temperatures and lower humidity (Schulze and Jordan 2003). Compared to *I. scapularis, A.*

americanum can tolerate dryer conditions, which may support its ability to hunt and travel longer distances during the day, seeking CO_2-emitting host sources (Schulze et al. 2001, Schulze and Jordan 2003).

A. americanum is known for its wide range of hosts and extreme host infestations. White-tailed deer often support all three life stages of the species while being a principal mode of transportation (Childs and Paddock 2003, Paddock and Yabsley 2007), and heavy tick burdens have led to the death of white-tailed deer fawns in Oklahoma (Bolte et al. 1970). When deer are excluded from an area, the tick population can be reduced, highlighting the significance of this host species (Ginsberg et al. 2002). Other common hosts include coyotes, red foxes, racoons, opossums, rodents, wild turkeys, and all life stages will bite humans (Kollars et al. 2000, Childs and Paddock 2003, Goddard and Varela-Stokes 2009). Schulze et al. (1986) found that New Jersey *A. americanum* larvae mostly infested white-footed mice while nymphs were most abundant on the eastern gray squirrel, white-footed mouse, and meadow vole. Conversely, adults infested eastern gray squirrels and opossums (Schulze et al. 1986).

While *A. americanum* was once only considered a nuisance species, it is now considered to be a tick of medical importance. It is capable of transmitting a variety of pathogens to humans that cause disease, and it is associated with a red meat allergy (Table 3). On Long Island, NY, adult and nymph tick pools had a 12.5% and 1.4% *E. chaffeensis* infection prevalence, respectively (Mixson et al. 2004). Over a seven-year period, a 12.9% infection rate of *E. chaffeensis* was reported in NY, second highest only to New Jersey (Mixson, 2006). Even though white-tailed deer are not a reservoir for *B. burgdorferi*, they support the transmission cycle of *E. chaffeensis* and can remain bacteremic for over three weeks (Dawson, 1994). In Oklahoma, average tick burdens were over 300 per deer (Bolte et al. 1970), increasing the potential for many of these ticks to become infected. Under laboratory conditions, *A. americanum* is competent to transmit *Rickettsia rickettsii* horizontally and vertically (Levin et al. 2017). In a tested subset of eggs, it also transmitted Di-6 and AZ-3 *R. rickettsii* isolates vertically at rates of 28% and 14%, respectively (Levin et al. 2017). Importantly, *A. americanum* is incompetent for *B. burgdorferi* (Mukolwe et al. 1992, Stromdahl et al. 2015), and the saliva of this species has shown cytotoxic effects towards *B. burgdorferi* (Ledin et al. 2005), aiding in the cessation of transmission.

A. americanum also causes Southern Tick-Associated Rash Illness (STARI), a Lyme disease-like rash and symptoms, but the causative agent remains elusive. It is possible the agent is *B. lonestari* which has been detected in *A. americanum*, but minimal conclusive research is available. *B. lonestari* was identified in both a patient presenting with STARI and from the embedded *A. americanum* (James et al. 2001). Also, a low prevalence of *B. lonestari* (0 to 3.1%) was detected in *A. americanum* from Georgia, Missouri, Texas, New Jersey, and New York (Barbour et al. 1996, Killmaster et al. 2014), and an estimated minimum infection rate was 8.4 per 1000 ticks from Tennessee (Stegall-Faulk et al. 2003). This demonstrates low but possible infection rates. More definitive research needs to be done to determine the causative agent of STARI and to implicate *A. americanum* for that agent.

Table 3. Diseases caused by *A. americanum*- transmitted pathogens.

Disease/Illness	Causative agent	Group	Citations
Ehrlichiosis	*E. chaffeensis, E. ewingii*	Bacterium	(Killmaster et al. 2014, Wright et al. 2014)
Heartland virus disease	Heartland virus	Virus	(Savage et al. 2016, Savage, Godsey, Tatman, et al. 2018)
Tularemia	*Francisella tularensis*	Bacterium	(Calhoun 1954, Mani et al. 2015)
Red meat allergy	Intolerance to galactosealpha-1,3-galactose (alpha-gal)[&]	NA	(Kinoshita and Newton 2019)
Southern Tick-Associated Rash Illness (STARI)	NA*	NA*	(Varela et al. 2004, Killmaster et al. 2014)
Bourbon virus disease	Bourbon virus	Virus	(Savage et al. 2017, Savage, Godsey, Panella, et al. 2018)

[&]Alpha-gal is a mammalian oligosaccharide epitope found in non-primate animals that humans may develop an allergic reaction to after consumption
*Inconclusive research has suggested the bacterium *B. lonestari*

Main methods for collecting *A. americanum* include dragging and CO_2 trapping. On Long Island, NY, *A. americanum* was collected on drag cloths alongside *I. scapularis* in June (Telford et al. 2019). In New Jersey, CO_2 traps were effective at collecting adults while dragging worked best for nymphs and larvae. Even though walking surveys can be useful for adult and nymph collections, dragging was still more efficient (Schulze et al. 1997). In areas where *I. scapularis* dominated, CO_2 effectively captured more *A. americanum*, likely due to the increased mobility and hunting nature of this species (Ginsberg and Ewing 1989b). Likewise, CO_2 traps effectively collected *A. americanum* in Tennessee (Stegall-Faulk et al. 2003).

Haemaphysalis longicornis

H. longicornis (the Asian longhorned tick) is native to eastern China, Japan, Korea, and the Russian Far East (Beard et al. 2018) and has successfully invaded and established in New Zealand and Australia (Hoogstraal et al. 1968, Heath 2013). The first case of *H. longicornis* in the United States outside of quarantine was in 2017 from a New Jersey sheep farm (Rainey et al. 2018); however, archived specimens revealed that *H. longicornis* was present in New Jersey since 2010 (Beard et al. 2018). Since 2017, twelve states in the United States confirmed populations of this invasive species: Arkansas, Connecticut, Delaware, Kentucky, Maryland, New Jersey, New York, North Carolina, Pennsylvania, Tennessee, Virginia, and West Virginia (United States Department of Agriculture 2019).

H. longicornis can demonstrate bisexual and parthenogenic reproductive tendencies (Heath 2016), and biological differences occur between both modes. Parthenogenic ticks are larger, have a longer developmental cycle, have a smaller percentage egg hatch rate, and have a longer interstadial period between the nymph and adult stages compared to bisexual ticks (Chen et al. 2012). The parthenogenic females also engorge more slowly and have a longer preoviposition period (Chen et al. 2012). Because of its ability to reproduce parthenogenically, it produces high numbers of offspring and causes extreme host infestation (Beard et al. 2018). In the United States, *H. longicornis* is only parthenogenic (Heath 2016, Rainey et al. 2018), with other parthenogenic populations detected in New Zealand, northeastern Russia, Australia, New Caledonia, Tonga, and Fiji (Hoogstraal et al. 1968). Bisexual and parthenogenic populations are in northeastern China and in Japan (bisexual in the south and parthenogenic in the north) (Hoogstraal et al. 1968).

The longevity of this species in the United States is underreported given its recent establishment in Northeastern states. In New Zealand, it can complete its life cycle in one year, although with optimal weather and host conditions, it may finish in as little as four months (Heath 2016). Additional research will be necessary to elucidate the life span of *H. longicornis* in the United States.

Because of the new invasion and continuing expansion, phenology data for *H. longicornis* in the Northeast United States is currently limited. In NYC, NY on Staten Island, peak nymph activity was mid-June to early July, compared to peak adult activity in mid-July. Peak larval activity was late July to early August (Tufts et al. 2019).

H. longicornis ticks are active in a wide range of habitats (Heath 2013), which are influenced by temperature, relative humidity, precipitation (Rochlin 2019), seasonality, and winter diapause. While *H. longicornis* is restricted to temperate areas (Chen et al. 2012), it can withstand a wide range of temperatures (−2°C to 40°C) (Heath 2016, Jiang et al. 2018), aiding its survival and possible distribution into southern Canada and to the Gulf Coast (Rochlin 2019). In New Jersey, *H. longicornis* was found in un-mowed grass (Rainey et al. 2018). On Staten Island, they were found in forested environments with leaf litter, grasslands, and both tall and mowed grass on residential properties (Tufts et al. 2019). Importantly, most residential properties that sampled positive for *H. longicornis* were in close proximity to parks (Tufts et al. 2019). Maxent models predict highly suitable habitat for *H. longicornis* in New York, New Jersey, and Arkansas and less suitability in Pennsylvania and West Virginia (Rochlin 2019).

Host associations for this species are both mammals and birds (Heath 2016), supporting the mobility of this tick and its possible dispersal within and to the United States and Canada (Hutcheson et al. 2019). All life stages can parasitize medium and large mammals (Tsunoda and Tatsuzawa 2004), and all three life stages of *H. longicornis* have been found on sheep in the Northeast US (Rainey et al. 2018). On Staten Island, *H. longicornis* was not found parasitizing any birds or white-footed mice; however, all life stages were collected from white-tailed deer. Whether immature stages feed only on deer or other unsampled mammals remains to be determined (Tufts et al. 2019). Field observations of *H. longicornis* ticks from New York showed that the adults were repelled by the presence of a human host (Sherpa 2019); however, the first recognized human bite from *H. longicornis* in the United States occurred in New York in June 2018 (Wormser et al. 2020).

H. longicornis is a tick species of medical and veterinary concern. In China, it transmits severe fever with thrombocytopenia syndrome virus (SFTSV) which leads to human hemorrhagic fever (Luo et al. 2015) and has a 30% case fatality rate (Yu et al. 2011). In Japan, *H. longicornis* was found infected with *R. japonica* in an area with high Japanese spotted fever cases (Tabara et al. 2011), and ticks from Japan showed competency for Langat virus and *Thogoto virus* (Yoshii et al. 2015, Talactac et al. 2017, 2018). *H. longicornis* can also transmit *Theileria orientalis* in cattle (Hammer et al. 2015, Heath 2016). High tick infestations can lead to livestock weakness and death, and it can cause economic damage to hides and loss of dairy production (Perera et al. 2014). In North Korea, a study found that blood-feeding *H. longicornis* on goats tested positive for *Anaplasma bovis, Bartonella grahamii, A. phagocytophilum, Bartonella henselae*, and *Borrelia spp*. (Kang et al. 2016), although there is no research on the capacity of *H. longicornis* to vector these pathogens to humans. There has also been evidence of a possible meat allergy associated with the bite from *H. longicornis* (Chinuki et al. 2016). Fortunately, while the larvae can acquire *B. burgdorferi*, the pathogen does not persist past the molting stage, and *H. longicornis* from NYS were not able to transmit *B. burgdorferi* (Breuner et al. 2020). To date, there has not been a documented case of *H. longicornis* transmitting any pathogens to humans in the United States. Nonetheless, the potential for co-feeding infections exists since *H. longicornis* was found co-feeding beside *A. americanum* and *I. scapularis* on deer in NY (Tufts et al. 2019).

Environmental sampling for *H. longicornis* includes dragging, flagging, CO_2 baited traps, and animal surveillance on companion, livestock, and wildlife animals (Beard et al. 2018, Rainey et al. 2018, Tufts et al. 2019) More research needs to be conducted for this species in the Northeast United States to determine the most efficacious sampling methods.

Tick Density and Exposure in Northeast United States Parks

Tick density and pathogen prevalence in United States public parks is variable, and the following studies report occurrence in Northeast parks.

From late May to early August in 2014 and 2015, nymphal tick density was measured in nine National Parks on the east coast in Northeastern and Mid-Atlantic states: Acadia, Catoctin Mountain, Fire Island National Seashore, Gettysburg National Military, Manassas National Battlefield, Monocacy National Battlefield, Prince William Forest, Rock Creek, and Shenandoah National Park. Drag sampling took place in high visitor use areas that were suitable for tick habitat, such as established trails in deciduous forests, and three 750 m drags were conducted twice a year where possible. In 2015, *I. scapularis* nymph density was between 0.27 (Gettysburg National Military Park) and 20.4 (Fire Island National Seashore) per 100 m^2. Pathogen prevalence for the total nymphs tested (n=1460) varied by pathogen species. *B. burgdorferi* was present in all areas where *I. scapularis* was located, and NIP across parks ranged from 3.2 to 35.6%. Additionally, *B. miyamotoi, A. phagocytophilum*, and *Babesia microti* were present at 60, 70, and 20% of parks, and NIP ranged from <1 to 4.4, 1 to 10.7, and <1 to 15%, respectively (Johnson, Graham, Boegler, et al. 2017). While this study shows a gradient of tick density and pathogen prevalence across parks, it does not detail visitor exposure to the tick habitats. Lacking a human behavior component, this study cannot quantify the number of park visitors at risk, and it cannot explain demographic exposure risk. Additionally, information on tick phenology is missing, which would impact visitor exposure to nymphs during peak activity.

In Pittsburgh, PA, 20 sites across four parks were sampled for ticks in a mix of interior woodland plots and ecotone edges during the appropriate phenology peaks. *I. scapularis* adults were present in 55% of the sites, predominately Highland Park (n=114), and density was 4.3x higher for edges compared to plots. Nymphs were present in 84% of the sites, mostly in Highland Park (n=193), and in greater density for plots compared to edges (1.7x). Approximately 52% of adults and 19.3% of nymphs were infected with *B. burgdorferi*, though no difference was observed across parks for adults. Interestingly, white-tailed deer were observed in all parks, yet the distribution of *I. scapularis* was unequal among parks. Because this study was conducted for only one year, tick density trends in these parks are unknown (Simmons et al. 2019). The four parks in this study represent green spaces within a city, but no information is provided on the quantity of visitors that may be at risk for exposure. The lack of data on park visitors in the tick collection sites makes it difficult to assess exposure risk for ticks and pathogens.

Twenty-four parks were sampled twice for nymphs between 30 May to 30 June in 2017 in Queens, the Bronx, and on Staten Island, New York. The 100 m drag sampling was conducted in continuous stretches of forest and along trail and forest edges. Seventeen of 24 parks presented with at least one *I. scapularis,* and 10 had established populations (>6 ticks). On Staten Island, the highest abundance of ticks was within the central and southern part of the island. The nymph infection prevalence of *B. burgdorferi* ranged from 8% (Willowbrook Park) to 40% (Blue Heron Park) (VanAcker et al. 2019). With uninterrupted forest grids, the sampling most likely excludes areas of high usage by park visitors, such as recreational areas and manicured vegetation spaces. Therefore, tick exposure risk for park visitors is reduced without visitor access to certain park areas. To understand risk for tick exposure in public parks, tick sampling should be performed in areas frequently used by visitors.

In Gettysburg National Military Park, PA, 12 sites were sampled for ticks by flagging a site for 30 sec, fifty times, for a total of 25 sampling mins per site. The sites were selected based on park visitor points of interest, tick habitat as described by employees, and employee work areas. The entomological risk index was calculated based on the number of infected nymphs per hour of habitat exposure. The majority of ticks collected (n=110; 78%) were *I. scapularis,* and the height of activity was between May and July. With an 18% *B. burgdorferi* infection rate for *I. scapularis* nymphs (n=13) and 27% for adults (n=11), the encounter rate for infected nymphs was 1.3 infected nymphs/hr during the 2009 nymphal season (Han et al. 2014). While the chosen locations were based on points of visitor interest, no information was provided on park usage within the sampled sites or habitats. Failing to describe park visitor usage of the sites limits the understanding of exposure risk where the investigators sampled. Opting to collect ticks by time instead of distance could bias the results based on the walking speed and distance travelled by the collector. In return, visitors may not experience the same tick encounter rate.

Eight parks located in Westchester County, New York, were selected based on high visitor usage or proximity to Lyme disease cases. Ticks were collected by dragging, and an encounter distance (meters dragged until encountering a tick) was calculated. *I. scapularis* was found in all but one park, representing 91.8% of the ticks collected. Two of the top three most attended parks had the highest *I. scapularis* populations, suggesting an increased risk of tick exposure in these parks. However, for most high attendance parks, there were fewer *I. scapularis,* possibly due to habitat alteration or decreasing hosts. Tick encounter distance in the highest risk parks was 36 to 118 m while parks at lowest risk had an encounter rate of 208 m to infinity (no ticks encountered). The sampling time varied by park from 6 hr 20 min to 35 hr 10 min (Falco and Fish 1989). While chosen parks were based on visitation frequency, the quantity of visitors was not calculated. Knowing demographic factors will clarify who is at-risk for tick encounter. Likewise, calculating the encounter distance is useful for knowing the likelihood of contacting a tick, but only if a person is following the same flagged trajectory. This study does not account for the length of time visitors spend in specific habitats nor the directional movement of visitors across different habitats. Crossing habitats and lingering in specific locations would influence the risk for tick exposure.

As highlighted in the previous studies, the tick population is not homogeneous, and it varies spatially and temporally within and across parks. Inconsistency in tick density between parks can be due to many factors such as variability in the host population, differences in host utilization of park habitats, and climatic variables like yearly precipitation events (Mount 1981). Tick surveys may also misrepresent the population if collectors are not sampling in areas where ticks are present or if the sampling effort is not high enough to capture the true population. The risk of human exposure may vary between parks, but measuring tick abundance and pathogen prevalence does not necessarily equate to human risk for tick or pathogen encounter. It is necessary to understand how humans utilize park areas and if their usage may be putting them at risk for tick exposure.

Visitor Use of Park Spaces

Observing human usage of public park spaces can help us understand where individuals spend their time and if those areas put park visitors at risk for tick exposure. Currently, no studies that I've found in the United States spatially map visitor usage of park spaces or detail time spent in specific park sites and vegetation habitats. However, some studies are available that describe trends in visitor preferences for park locations.

In Edinburgh, Scotland and Ljubljana, Slovenia visitor usage was mapped during four time periods: 10-12 pm, 12-2 pm, 2-4 pm, and 4-7 pm. Each “sub-area” within the parks was observed for 10 min on a weekday and weekend, and park visitor movement in that area was recorded. Demographic information, activity type, and duration of time engaging in an activity was detailed for each visitor. The researchers found that open green spaces were nearly always occupied by park visitors, and people tended to congregate around edges, avoiding large grassy areas unless trees were present. As the size of the open space increased, the size of the group engaging in a sport or activity increased, and men were more often engaging in larger group activities. Activities that involved long-stay occupancy were football and children playing (i.e. hide and seek) (Goličnik and Ward Thompson 2010). While this study elucidates park usage on a fine spatial scale, it does not examine habitat exposure to analyze elapsed time spent in specific vegetation types or on built environments. The duration of time measured was classified into four categories with the cutoff measured at five minutes, and this may not be a long enough observation period to adequately capture individuals’ activities or length of stay.

Preference for specific habitats is influenced by demographic factors, and this could impact if and how individuals choose to use park spaces. In Norway, surveyed individuals who were more educated and middle-aged claimed that natural landscapes within a popular park were more optimal for recreational use, but older people disliked these habitats, potentially due to having limited motor capabilities that inhibit access to certain areas (Bjerke et al. 2006). In Finland, middle-aged and older individuals thought the removal of natural undergrowth improved the scenic beauty of a landscape, while younger people did not (Tahvanainen et al. 2001). Similarly, in the United States, younger age groups preferred photos of natural habitats compared to older individuals (Lyons 1983, Zube et al. 1983). While all of these studies show that age group impacts favored habitats, picture preference via questionnaires may not translate into physical use, and none of these studies demonstrate how frequently or how long individuals utilize their preferred areas.

Park visitor demographics influence activities which could impact length of stay in a park space (Goličnik and Ward Thompson 2010). In eight Viennese parks, the majority of visitors were walkers; however, individuals ages 30 to 43 mostly visited green spaces with children, visitors 44 to 59 years of age walked dogs or cycled, and those over 60 walked without a child or dog (Arnberger and Eder 2011). In Kansas City, Missouri, males and females went to the parks equally; however, adults and children went more often than teens and seniors. While most individuals participated in sedentary behavior (53%), males engaged in more moderate to vigorous activity compared to females, and children and teens were more active than seniors and adults (Kaczynski et al. 2011). In a literature review, the elderly went to parks less frequently compared to other groups, males frequented parks more often than females, and park visitor activity was highly variable (Evenson et al. 2016). In 18 Chicago and 10 Tampa parks in the United States, adults, children, and men went to the parks the most often. The majority were engaged in sedentary behavior (65%), while 23% walked and 11% did vigorous activity. Children and males were more likely to partake in vigorous activities compared to adults and women in Tampa parks. Overall energy expenditure varied by neighborhood type (ethnicity and income) and activity zones available, indicating that variability in park facilities based on socioeconomics could impact long-term health and activities (Floyd et al. 2008).

Knowledge, Attitude, and Practices

Understanding how people perceive risk and how that perception influences their behavior is important for determining if and how an individual takes precaution for TBDs. Knowledge, Attitudes, and Practices (KAP) surveys are an ideal way to determine if an individual's level of knowledge and attitude about TBDs affects behavior (Riccò et al. 2019). By understanding these knowledge and practice gaps, public outreach programs can better inform the community on proper protection mechanisms through education.

Successful studies have used KAPs to determine factors influencing tick preventative behavior. One such study revealed that only 25% (n=152) of Florida Fish and Wildlife and State Park employees received TBD training. Within the study population, most individuals were most aware about checking ticks on their skin and least aware about tucking socks into pants to reduce tick exposure. Those who most checked for ticks on the skin had the highest knowledge about TBD personal protective behavior (PPB), they perceived themselves to be more at-risk, they had a higher intention of taking action to prevent tick bites, and they believed their action would be efficacious in reducing tick bites. Predictors of using insect repellent were being female, having a high intention of taking action to prevent tick bites, and perceiving many benefits of taking action against TBDs. Predictors of practicing PPB were having high knowledge of TBD PPB, perceiving TBD risk as high, having high intention of taking action against ticks, and perceiving many benefits of engaging in PPB against ticks (Donohoe et al. 2018).

In the Gettysburg National Military Park, PA, the majority of employees who completed the KAP survey were maintenance (n=38) and park ranger employees (n=28), and they were predominantly male (n=61;78%) between 45-54 years old (n=29; 38%). The majority worked for the park for over ten years and worked an average of 30+ hours a week (n=44; 56%).

Approximately 82% of employees considered Lyme disease to be very serious at the park, 84% had found an unattached tick in the past year, 62% believed they were somewhat or very likely to acquire Lyme disease while at the park, and 11% had been diagnosed with Lyme disease in the past. Practicing protective measures was irregular among employees, and the top measures practiced were tick checks and wearing long pants. Employees did not often use repellent or report tucking pants into socks (Han et al. 2014).

In Finland, individuals in two different cities were most knowledgeable about the tick-borne encephalitis (TBE) vaccination (n=88; 88%) and wearing long sleeves and pants (n=80; 81%). Most reported quickly removing ticks if they were to find ticks attached (97%). If respondents believed that vaccination protected against tick-borne encephalitis, they were more likely to be vaccinated against it. Vaccinated individuals were more likely to think a rash was not associated with TBE. Moreover, most people were unclear on the appropriate treatment of TBE or if the vaccine can also provide protection against ticks (Zöldi et al. 2017).

A study in Sweden compared tick preventative practices in areas of different levels of tick and TBE risk (emerging risk, tick risk, TBE risk). Most respondents checked for ticks (63%), used protective clothes (64%), or avoided tick habitat (48%). Less tucked pants into socks (18%) or used repellent (16%). Tick bites were the most common in areas of high tick and TBE risk, and knowledge of and experience with TBDs increased as the level of risk for exposure increased. Unfortunately, even though knowledge and experiences increased with risk-level, this did not statistically influence tick preventative behavior. Avoiding tick habitat, using protective clothing, and tucking pants into socks was not statistically different among the different risk-type locations, however checking for ticks did increase in tick and TBE risk areas compared to emerging risk areas. While repellent use was higher in emerging risk areas, this may be confounded by mosquito prevention (Slunge and Boman 2018).

In Connecticut, 275 community event attendees were interviewed. Of all tick preventative behaviors, respondents conducted tick checks the most (n=167; 68%) and used repellent the least (n=92; 38%). Most believed tick checks to be effective at preventing tick bites (n=219; 86.6%). However, people thought conducting tick checks, showering within two hours after going outdoors, wearing protective clothing, and using repellent were burdensome to practice (25%; 25%, 28%, 26%, respectively). Individuals who were tested for a TBD scored higher on knowledge-based questions compared to individuals who were never tested for a TBD. Those who knew more about Lyme disease practiced more tick checks, and people mostly believed tick prevention methods to be effective. Those who believed it to be effective were more likely to perform the preventative behavior (Butler et al. 2016).

St. Louis, Missouri is a metropolitan city with different types of recreational areas: rural, suburban, and exurban (low density land use outside urban settings) areas. Park visitors in rural parks were able to name more TBDs compared to visitors in suburban and exurban parks. Overall, people expressed low concern over being bitten by a tick (n=126; 52.9%), and attitudes varied by age group: younger people were less concerned about contracting Lyme disease compared to older groups. Most park visitors stayed on the trails (n=130; 54.6%), practiced tick checks (n=125; 52.5%), avoided wooded areas (n=121; 52.8%), and used repellents (n=112; 47.1%). Fewer reported wearing long sleeves (n=59; 24.8%) and tucking pants into socks (n=40; 16.8%). Exurban park visitors practiced tick checks and wore repellent the most. Individuals in rural parks avoided tick habitat the least. People who were the most concerned about being bitten by a tick were more likely to perform tick checks and wear the proper clothing and repellent.

Likewise, the visitors who attended the parks most frequently avoided tick habitat the most (Bayles et al. 2013).

In Delaware where Lyme disease is prevalent, most people reported showering after going outdoors (40.4%), using repellent (22.4%), conducting tick checks (22.2%), and wearing light-colored clothing as tick preventative measures (16.6%). Only 19% (n=341) of respondents believed they could protect themselves against Lyme disease. Individuals over 45 years old were more likely to use repellents (54%) and check for ticks (56.1%), and older age groups were more aware about ticks. Females reported that ticks were problematic and were more likely to use repellent, shower, wear the appropriate clothing, and tuck pants into socks compared to males. Younger respondents, blacks, and males spent the most time outside during the summer, and the areas most utilized were paved urban areas, private suburban lawns, public wooded areas, and community parks (Gupta et al. 2018).

On a ferry in Massachusetts traveling from Martha's Vineyard to Woods Hole, most respondents were female, white, college-educated, and visitors vacationing. Most scored 73% on the knowledge test regarding Lyme disease and *I. scapularis*. Respondents reported doing tick preventative behaviors inconsistently and less than 50% of the time, and they believed their risk for getting Lyme disease was low, suggesting that non-residents may be less aware of the risk associated with ticks in an unfamiliar area. The majority of respondents believed Lyme disease was serious even though few were diagnosed with it. Most believed they could reduce their risk of exposure by conducting tick checks, wearing long pants in socks, and using repellents (82%, 85%, and 73%, respectively). Overall, knowledge about Lyme disease and preventative behaviors did not decrease risky behavior, but having personal acquaintances with Lyme disease, perceiving precautionary behavior as outweighing the inconvenience, and believing Lyme disease was serious predicted risk-reducing behavior. Unfortunately, over half of ferry passengers believed doing tick preventative actions would be inconvenient (Shadick et al. 1997).

Tick Prevention

Compared to adults, nymphal ticks are less likely to be detected and removed before successful pathogen transmission due to their small size, so tick and host habitat management strategies can help reduce exposure in parks and at home. Using integrated pest management (IPM) approaches to decrease tick abundance is an important approach for tick control. IPM practices include: reducing hosts by excluding hosts from areas, eliminating hosts and host habitats, treating hosts with acaricides, treating tick habitats with acaricides, modifying the landscape to decrease habitat suitability, and using personal protective measures (Maupin et al. 1991, Stafford 2007). Leaf litter removal in New Jersey and rodent-targeted acaricides via bait boxes in Connecticut were effective in reducing *I. scapularis* (Schulze et al. 1995, Dolan et al. 2004). In Oklahoma, vegetative management practices such as over and understory removal and frequent mowing controlled 76-93% of *A. americanum* (Mount 1981). Research on *H. longicornis* IPM measures is currently unavailable in the United States, however, since the white-tailed deer is a prominent host for this species (United States Department of Agriculture 2020), controlling the deer population could prove beneficial. While various IPM measures have proven effective at tick reduction, park visitors only have control over the personal protective measures they utilize and IPM approaches used at their home. Therefore, the responsibility of any park habitat manipulation, host or tick control, or acaricide treatments for hosts or ticks falls on the parks. To improve park visitor usage of personal protective measures, parks can offer educational materials to inform visitors of tick and TBD risk.

Education and outreach are necessary to inform the public about tick presence, TBD severity, and tick exposure reduction. A few studies have shown that school-based educational interventions can improve tick preventative behavior in children (Beaujean et al. 2016, Shadick et al. 2016). Educational resources were developed and tailored to three different groups by the Cornell Cooperative Extension of Delaware and the Delaware County Public Health department: parents, campers, and camp staff of 4-H camps. A post-camp survey assessed whether the information was used. Most parents (81%) reported receiving materials and reading them, and of those who read them, the caregivers discussed tick checks (67%), using repellent (62%), wearing protective clothing (56%), and responding to a tick or tick bite (56%) with their campers. Less frequently, the caregivers discussed tick characteristics (36%) and tick habitats (35%). The information greatly influenced parents to encourage their campers to shower (64%), and it moderately to greatly influenced them to pack their campers long-sleeved clothes (72%). Of the 130 camper surveys, 86% reported discussing ticks with their parents prior to camp, and the entertaining skit was more effective than camp staff at teaching new information about ticks (Crim et al. 2018).

Personal protection measures include wearing light colored clothing to readily see ticks, tucking pants into socks to limit tick access to the skin, avoiding tick habitats (such as wooded areas with brush and leaf litter), remaining on the center of trails, conducting full body tick checks, showering after going outdoors, using EPA-registered insect repellents with approved active ingredients such as DEET, picaridin, oil of lemon eucalyptus, para-methane-diol, or 2-undecanone (Stafford et al. 2017, Centers for Disease Control and Prevention 2019g), and using long-lasting permethrin-treated uniforms (Sullivan et al. 2019). Little research on the success of non-repellent personal protective measures is available, and currently no vaccines for TBDs are available in the United States.

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CHAPTER 2

ASSESSING KNOWLEDGE, ATTITUDES, PRACTICES, AND THE RISK OF PARK VISITOR TICK EXPOSURE ON STATEN ISLAND, NEW YORK

Introduction

The distribution of ticks in the United States (US) continues to expand, putting individuals at risk for tick exposure and tick-borne diseases (TBD). Lyme disease is the most prevalent vector-borne disease in the US, with an estimated 300,000 cases occurring each year, predominately in the New England, Mid-Atlantic, and Upper-Midwest regions (Centers for Disease Control and Prevention 2019). While being in green spaces, such as forests and parks, has shown health benefits like stress reduction (Ward Thompson et al. 2012), mental fatigue relief (Kaplan 1995, Hartig et al. 2003), violence reduction (Garvin et al. 2013), and happiness improvement (Yulistia Rahayu et al. 2019), green spaces may inadvertently put people at risk for exposure to ticks and TBDs.

There are multiple tick species in New York State (NYS), including three medically relevant species that pose a risk to park visitors: *Ixodes scapularis* (blacklegged or deer tick), *Amblyomma americanum* (lone star tick), and *Haemaphysalis longicornis* (Asian longhorned tick). All three species can parasitize humans and transmit pathogens that cause disease in their native ranges. As humans engage in outdoor activities during tick questing periods, including visiting public parks, they risk exposure to these species and any pathogens the ticks may carry.

With no human vaccines available for TBDs in the US and only a tick-borne encephalitis vaccine available in Europe, risk reduction involves diminishing tick density and decreasing human-tick interaction. Therefore, it is crucial to know tick distribution and ecology and understand the likelihood of park visitor exposure to ticks (risk) based on how visitors utilize areas that have a greater abundance of ticks (i.e. hazardous areas). In addition, it is important to determine the drivers of tick preventative behavior among park visitors.

Tick populations are heterogeneous and parks are disproportionately affected by tick and pathogen prevalence (Johnson et al. 2017, Simmons et al. 2019, VanAcker et al. 2019). Human exposure risk to ticks and pathogens has been calculated in public areas by determining the infected tick encounter rate per hour (Han et al. 2014) and tick encounter distance (number of meters passed until encountering a tick) on frequently used trails (Falco and Fish 1989). However, these studies only use acarological measures and do not examine human usage of the sampled areas.

Knowledge, attitude, and practice (KAP) surveys can identify gaps in the public's knowledge and response to tick exposure risk. Current KAP research demonstrates that respondents minimally and irregularly exercise tick preventative practices (Shadick et al. 1997, Bayles et al. 2013). Likewise, predictors of practicing tick preventative measures vary by study and are influenced by respondents' experience, knowledge, and attitudes (Shadick et al. 1997, Bayles et al. 2013, Donohoe et al. 2018). Information on the effect of knowledge and attitudes on practices is not available for Staten Island, New York, a residential island where there are many urban public parks and where the tick population is distributed unequally.

Due to the variation in tick density across parks, the difference in drivers influencing tick preventative practices, and the lack of studies linking human behavior to tick exposure risk, I sought to determine 1) the distribution of tick species in select Staten Island parks, 2) areas of high and low tick hazard (changes in tick density by park, site type, and habitat), 3) the identity of at-risk visitors based hazardous area usage and demographics, and 4) the influence of park visitor knowledge, attitudes, past experiences, and demographics on their tick prevention practices. I conducted my study from 20 May to 19 August 2019.

Materials and Methods

Human Subjects Approvals

Protocols and procedures involving human subjects were reviewed by the Institutional Review Board of Cornell University, Protocol #: 190400878, and deemed exempt.

Field Sites

Staten Island is one of five boroughs in New York City, approximately 58.4 square miles in area and is located south of Manhattan. As of 2018, it has an estimated population of 476,179 with 75.2% of the population being White or Caucasian, 11.7% Black or African American, 10.2% Asian, and 18.7% identifying as Hispanic or Latino ("U.S. Census Bureau QuickFacts: Richmond County (Staten Island Borough), New York" 2019). Prior to implementing this study and with the help of my collaborators, I selected three public parks on Staten Island: Clove Lakes Park (40°37'06.2"N 74°06'27.8"W), Willowbrook Park (40°36'15.0"N 74°09'31.1"W), and Conference House Park (40°30'08.1"N 74°15'06.3"W), shown in Figure 1. These parks were selected due to their observed high volume of park visitors and variation in tick density (VanAcker et al. 2019).

Figure 1. Park locations on Staten Island. A: Clove Lakes; B: Willowbrook; C: Conference House.

Clove Lakes Park was the northern-most park sampled in the Sunnyside neighborhood, with an approximate area of 0.94 km^2. It is characterized by three lakes, woodland forests, and a mixture of paved and non-paved walking paths. This was the second largest park in our study, and it had the most available open spaces for social events and large sporting activities. There were designated barbeque locations, basketball courts, boat rentals, fishing opportunities, and frequently scheduled races and other park activities.

Willowbrook Park is approximately 1.05 km^2 and is more centrally located on Staten Island within the Greenbelt. While this was our largest park, the majority of it is inaccessible forest with one natural walking trail extending for seven miles. In the area most accessible to park visitors, there is one lake circled by a paved walking path, a carousel, abundant waterfowl, and fishing opportunities.

Conference House Park was our southern-most park with an area of approximately 0.51 km^2, located in Tottenville and extending around the southern tip of Staten Island. This park contains sand dunes, sandy beaches, coastal meadows, wetlands, a playground, and a few open grass areas. Events held at the historic Conference House, such as public movie screenings, tours, and orchestras, draw in large groups of people.

Specific sites were selected within each park based on the potential for human use (e.g. walking trails and open spaces, excluding inaccessible forested locations) and tick habitat. I established six sites at Clove Lakes (three open spaces and three natural trails) and four sites at both Willowbrook and Conference House (two open spaces and two natural trails each). Additional trails were included in Clove Lakes after the deconstruction of prior selected trails. Site descriptions are detailed in the Table 4.

Table 4. Description of the 16 sites used in this study.

Park	Site	Coordinates	Description
Clove Lakes	Open Space 1	*40°37'27.9"N 74°07'10.3" W*	Contains one paved pathway extending through the site with a large mowed green space that is bordered by a lake on one side. The opposite side is a wood line. There are two locations for exercise.
	Open Space 2	*40°37'22.8"N 74°07'02.0" W*	Includes one paved pathway that branches to lake access. Habitat is mainly mowed lawn space but is bordered by a wooded hillside with leaf litter.
	Open Space 3	*40°37'04.0"N 74°06'39.1" W*	Contains 14 picnic tables in an irregularly mowed grassy area. Two green spaces are dissected with a paved pathway, and the whole space is surrounded by woods. A natural trail borders one side.
	Trail 1	*40°37'12.0"N 74°06'49.9" W*	Natural trail characterized by shade and leaf litter. Entrance is near the Clove Lake.
	Trail 2	*40°37'05.5"N 74°06'47.0" W*	Natural trail characterized by shade and leaf litter. Entrance is near Open Space 3.
	Trail 3	*40°37'08.2"N 74°06'31.1" W*	Natural trail running parallel to paved trail at the main park entrance.
	Trail 3 ext	*40°37'12.6"N 74°06'42.9" W*	Natural trail that continues after Trail 3 that runs in between unmaintained herbaceous vegetation, parallel to a steam. This was added later in the season when previous trails were closed for renovation.
	Trail 6	*40°37'05.6"N 74°06'41.8" W*	Natural trail that is covered in leaf litter. This runs through the woods and intersects Trail 2. This was added after the closing of Trail 1 and 2 for renovation.
Conference House	Open Space 1	*40°30'10.8"N 74°15'13.0" W*	Characterized by a large mowed lawn, a community garden, two natural trails, and beach access. The historical Conference House is located here and attracts many visitors for recreational activities
	Open Space 2	*40°29'57.0"N 74°14'41.6" W*	Characterized by the Lenape Playground. Contained in this space is a mixture of mowed grass, a tall grass border, and large impenetrable ground space for the playground.

	Trail 1	*40°30'07.4"N 74°15'06.4" W*	Natural trail lined by forest and tall grass. Trail head begins at visitor center and runs along beach, the sand dunes, wetland, and meadow.
	Trail 2	*40°29'54.6"N 74°14'46.5" W*	Trail head located near the playground and wetland; characterized by tall grass with beach access.
Willowbrook	Open Space 1	*40°36'25.3"N 74°09'26.7" W*	Near park entrance and characterized by mowed lawn space, multiple paved pathway entrances, a lake, and one natural trail.
	Open Space 2	*40°36'11.0"N 74°09'30.0" W*	A large, shaded, mowed grassy space with 24 picnic tables, a woodline, natural trail access, and a Carousel attraction.
	Trail 1	*40°36'18.8"N 74°09'27.8" W*	Natural wooded trail that runs alongside the lake, connecting Open Space 1 to the visitor center.
	Trail 2	*40°36'06.7"N 74°09'26.2" W*	Forested trail located on the edge of Open Space 2; 7.6 miles in length and characterized by leaf litter and shade

From 20 May to 19 August 2019, I visited each park approximately fourteen times, twice per weekday, to ensure equal park sampling on weekday and weekend. My park visitation schedule was dependent on weather, staff availability, and day of the week.

Tick Collections

I used a tick drag made from a 1 m^2 white corduroy cloth with one end containing a sleeve for a wooden dowel rod that was connected to a rope for pulling the drag along the ground. The trailing end of the drag cloth was fastened with small weights. I dragged the cloth along the ground in 100 m transects, checking for and removing attached ticks every 20 m (Rulison et al. 2013, Tufts et al. 2019, VanAcker et al. 2019). We mapped the drag distance using BasicAirData GPS Logger ver. 2.2.4 app for Android and GPS Tracker Pro app for iPhone 6s, and I verified the length of the transects using the program Garmin BaseCamp 4.8.3. I did not drag if conditions were wet, and I dragged each site once a week, weather and staff permitting, including additional dragging transects around the parks when able. Drags were restricted to areas where park visitors frequent to gauge risk for tick interaction (e.g. public trails, open lawn spaces, etc.), and each type of habitat available per site was dragged at least once a week. I collected at least three drags per site, and for woodline and trail transects, I ensured a 10 m distance separation between consecutive transects.

From 20 May to 23 June and after 27 July, all ticks were removed from the drag cloth and stored in 100% ethanol. In areas of high larval density, larvae were collected using clear tape or lint roller when necessary. Larvae collected from tape and lint roller were removed and stored in ethanol. I identified the ticks by species and sex using a Wild Heerbrugg Switzerland M5-23616 microscope and appropriate taxonomic keys (Keirans and Litwak 1989). From 23 June to 27 July, all nymphs and adults were collected alive for future blood-meal analyses at Columbia University, New York. Ticks were stored in clear tubes with one end open for air flow that was capped with a chiffon cover to prevent escape. Tubes were placed in a plastic bag with a moist paper towel to keep the ticks from desiccating until they were transferred into centrifuge tubes and frozen for blood-meal analyses.

On 1 July, Clove Lakes Trail 1 was under construction during the evening interval, and shortly after Trail 2 was under construction. Because they were stripped of vegetation and converted into built trails, I no longer sampled these trails after 21 July. Consequently, I added additional trails: Trail 3 extension (ext) and Trail 6. After 30 July, Trail 3 ext was also under construction.

Habitat Classification

The habitat in each site was classified based on five categories: maintained grass, unmaintained herbaceous, leaf litter, bare earth, and built (Table 5). I also recorded if I dragged an edge, indicating the habitat of the drag and the two habitats encompassing the edge (e.g. unmaintained herbaceous drag in between maintained grass and a forest). With this classification, I dragged all habitats in the sites to assess tick abundance, and I tracked human movement into these habitats to establish potential risk for ticks. Clove Lakes and Willowbrook had three different drag habitats: leaf litter, maintained grass, and unmaintained herbaceous. Conference House had two: maintained grass and unmaintained herbaceous. Figure 2 shows the number of drags performed in each park and site type in addition to the number of drags performed within the site types that had edges.

Table 5. Description of habitats classified in the park sites.

Habitat	Description
Bare Earth	Packed earth stripped of vegetation from overuse
Built	Environments void of plant material due to paved and other man-made, built environments
Ecotone Edge	Two habitats converging (e.g. forest alongside maintained grass).
Leaf Litter	Layer of leaf material, typically found under tree canopy
Maintained Grass	Non-woody graminoids generally characterizing mowed lawn space
Unmaintained Herbaceous	Non-woody herbaceous plants, a mixture of short weeds under 3 ft and over 3 ft

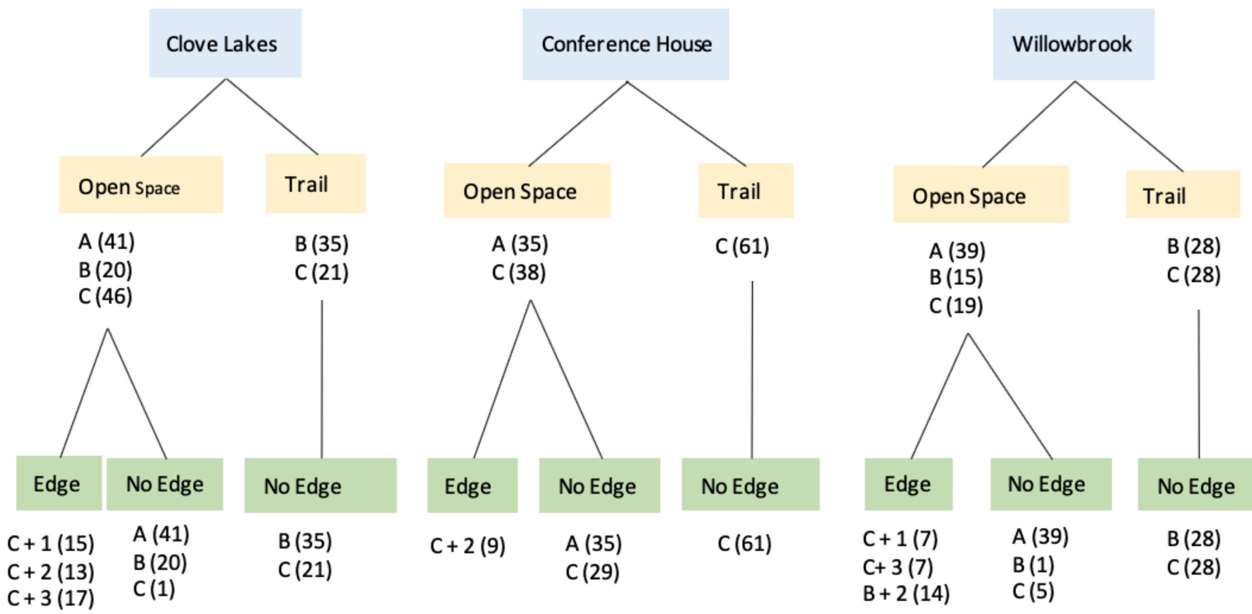

Figure 2. The number of drags (n) conducted in each site type (yellow) within each park (blue). The drag habitats found across the parks were A) maintained grass, B) leaf litter, and C) unmaintained herbaceous. At the edge of open spaces, the drag habitat comprised of the habitat where the drag was performed, but the habitat on either side of the drag was also recorded to characterize edge type. Edge drag habitats could be found in between 1) built and forest, 2) maintained grass and forest, or 3) maintained grass and water environments.

Unmaintained herbaceous habitats included common plants such as multiflora rose (*Rosa multiflora)*, poison ivy (*Toxicodendron radicans*), Japanese stiltgrass (*Microstegium vimineum*), jewelweed (*Impatiens capensis*), mugwort (*Artemisia vulgaris*), Japanese honeysuckle (*Lonicera spp*.), porcelain berry (*Ampelopsis brevipedunculata*), Japanese wineberry (*Rubus phoenicolasius*), Virginia creeper (*Parthenocissus quinquefolia*), smartweed (*Persicaria lapathifolia*), Japanese knotweed (*Reynoutria japonica*), blackberry (*Rubus spp.*), ragweed

(*Ambrosia spp.),* goldenrod (*Solidago spp*.), milkweed (*Asclepias syriacasedge*), nettle (*Urtica dioica*), and wild sarsaparilla (*Aralia nudicaulis*). Leaf litter included oak (*Quercus spp.*), red oak (*Quercus rubra*), beech (*Fagus grandifolia*), maple (*Acer spp.*), and pine (*Pinus spp.).* Maintained grass habitats were comprised of various graminoid species.

Pathogen Testing

A subset of the adult *H. longicornis* (n=127) was saved for pathogen testing and stored in ethanol. Pools of up to six ticks were separated by date, park, and site and submitted to the Animal Health Diagnostic Center at Cornell University to be tested for *A. phagocytophilum, B. microti, Bartonella spp., B. burgdorferi, B. mayonii, B. miyamotoi, E. canis, E. chaffeensis, E. ewingii,* Heartland virus, *Mycoplasma haemocanis,* Powassan virus, *Rickettsia* spotted fever group, *Rickettsia spp.,* severe fever with thrombocytopenia syndrome virus, and *Theileria orientalis*.

Park Visitor Observations

I established park usage by visiting each site per park three times a day during specific time intervals: 9am-12pm, 12pm-3pm, 3pm-6pm. This approach was adapted from Goličnik & Ward Thompson (2010). I observed each site for 30 minutes, once per time interval. In certain circumstances when observations for each site were incomplete (e.g. weather or staff shortage), I returned to finish those sites later in the season. For open sites, I designed paper maps with landmark locations to track the directional movement of visitors and the elapsed time each visitor occupied a habitat within the site (Figure 3). On an accompanying spreadsheet, I noted the following: entrance/exit time of individual, dominant activity, owning a dog or having a stroller, estimated age range in 10-year intervals, and gender. Because ages were estimated, they were converted into four categories: child (0-10), teen (10-20), adult (20-60), and senior (60+). For trail sites, I only noted entrance/exit time, age range, and dominant activity. During observations, I remained removed to avoid influencing the natural behavior of the park visitors, and I did not interact with the visitors in any way, removing individuals from the study who approached me

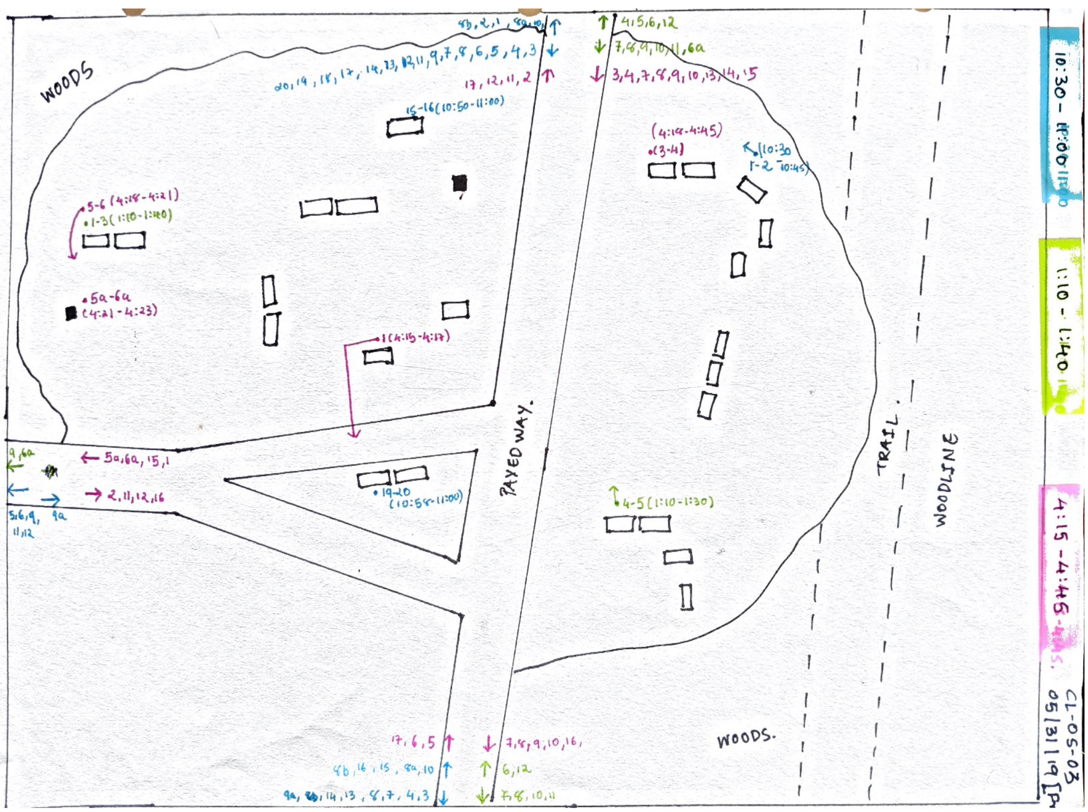

Figure 3. Map of park visitor movement in Clove Lakes Open Space #3. Human movement was mapped using arrows to denote the directional movement of each individual. Elapsed time was noted when visitors remained in one location. All daily time intervals for one site are represented: blue= 9am-12pm, green=12pm-3pm, pink=3pm-6pm.

Knowledge, Attitudes, and Practices Survey

I conducted a semi-structured interview using a 10-minute questionnaire to assess knowledge, attitudes, and practices regarding tick prevention. The questionnaire comprised 35 questions related to individual knowledge of ticks and tick-borne diseases, attitudes about perceived risk and severity, tick prevention behavior, and demographics (Appendix 1). Questions involved a mix of open-ended, close-ended ordered, and close-ended unordered responses. Demographic and background questions included age, gender, self-identification as Hispanic or Latino, ethnicity, highest level of education received, nearest intersection to the home, residency type within Staten Island, visitation frequency in the park, activities engaged in at the park, and source of information for ticks and tick-borne diseases. Knowledge questions included tick identification, identifying the tick transmitting Lyme disease (Figure 4), tick habitat, tick exposure on Staten Island, acquisition of the Lyme bacterium, prevention methods, and tick removal. Attitude questions included perceived severity of tick-borne diseases on Staten Island, perceived likelihood of tick encounter, reasons for not checking for ticks, and concerns about repellent use. Practice questions included frequency of repellent use, personal protection measures against ticks, and frequency of tick checks.

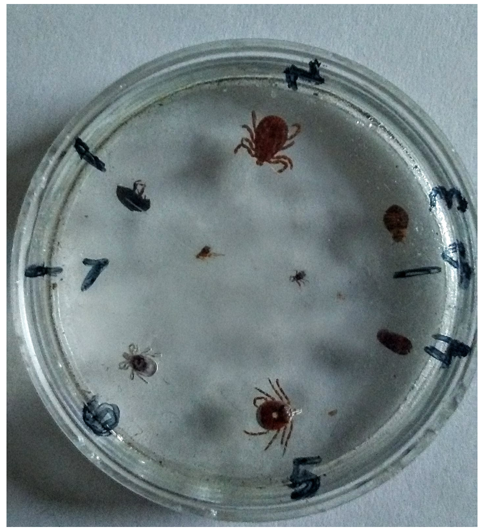

Figure 4. Arthropod samples including ticks and non-tick specimens. Respondents were asked to distinguish which were ticks given 1) Eastern ash bark beetle, 2) American dog tick adult, 3) swallow bug, 4) drugstore bug, 5) lone star tick adult, 6) deer tick adult, 7) flea, and 8) deer tick nymph.

Prior to administering the questionnaire, my team was trained in standardizing the delivery of the surveys and avoiding biases. I piloted the questionnaire to improve the oral delivery and length of delivery and wore institutional clothing with a name tag to help improve response rate.

Participants were recruited by convenience sampling. Individuals who were not actively engaged in an activity (e.g. talking on the phone, running, playing sports, etc.) were approached for the survey, and I noted all refusals and refusal reasonings. I explained the purpose of the study and only interviewed individuals over 18 years old who orally gave consent to be interviewed. Individuals were able to stop the survey at any time. With groups of individuals, I only recorded the answers of one visitor.

Open-ended responses were grouped into categories and given a 0 or 1 if the respondents verbalized the response. Similarly, close-ended unordered questions were given a 0 or 1 for verbalizing the response, and close-ended ordinal questions were recorded on a Likert scale.

Data Analysis

Analyses were performed in RStudio 2019 (R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/) using the following packages: dplyr, MASS, emmeans, MuMIn, car, dunn.test, and multcompView (Dinno 2017, Bartoń 2019, Graves et al. 2019, Ripley et al. 2019, Fox et al. 2020, François et al. 2020, Lenth et al. 2020).

Tick counts within parks, site types, and drag habitats were compared using a non-parametric Kruskal-Wallis test with a post-hoc Dunn's test. Because tick counts showed an overdispersion of zero counts, a negative binomial model was selected for determining the variables that best predicted tick counts for each species. Since sampling predominantly occurred during the nymphal period, and the entire peak was collected for all species, the analysis focused only on nymphal data. The package and function MASS: glm.nb in R was used to create the full negative binomial model for each species. MuMIn: dredge was used to determine the best model based on the lowest Akaike's Information Criterion (AIC)(Burnham KP and Anderson DR 2002), and model rankings are shown in Appendix 2. Variables used in the models were park, drag habitat, site type, and dragging distance (m^2). The nymphal peak for *I. scapularis* ended at week 10, so weeks 11 and 12 were removed from the analysis for this species.

Differences in visitation counts in parks, sites, habitats, and hazardous habitat exposure time were compared by gender and across age groups. A one-sample proportion test was used to compare the proportion of females and males visiting each park, habitat, and site type (RStudio:

prop.test). Within-group proportions for gender in each site and habitat were compared using a two-sample proportion test with a continuity correction (RStudio: prop.test). For age group, a generalized linear model with a poisson distribution was used to compare visitation counts in each site type and habitat. To determine whether mean elapsed time differed for age groups and gender in open spaces and habitat type, I used a type three ANOVA test followed by pairwise comparisons using the R package “emmeans”.

The KAP survey questions were organized into five sections: demographics, prior experience, knowledge, attitudes, and practices. Demographic questions included race, gender, age, education, and self-identification as Hispanic or Latino. Race was converted into a binomial variable and Hispanic/Latino was removed since the majority of respondents were white (58.9%) and non-Hispanic (80.5%). Education responses were grouped into “High school or less”, “Some college/Associates”, “Bachelors”, and “Graduate”. Age was categorized into six groups: 18-28, 29-39, 40-50, 51-61, 62-72, and 73-83. Questions related to prior tick experience were grouped and given a score from 0 to 4 (if yes to all, score=4). This included whether the respondent had seen a tick before, found a tick on a pet or household member, and whether someone in the home had been diagnosed with Lyme disease. Knowledge questions were scored based on correctness, and individuals received one point per correct response. Identification knowledge score was out of sixteen points, and individuals received one point for every specimen they correctly determined was a tick, and one point for every non-tick they identified correctly. Respondents received a tick habitat and tick infection score for every correct habitat they identified where ticks could be found and every correct response for how ticks can become infected with the Lyme bacterium. They also received a score for the total number of correct tick prevention methods they could identify. Questions regarding knowledge and practices for tick prevention methods were open-ended. Some individuals reported practicing certain prevention methods in the practices portion of the survey but failed to report knowing about these methods in the knowledge section. In these circumstances, individual knowledge scores were positively adjusted to reflect practicing the behavior. Attitude questions involving perceived severity of tick-transmitted diseases on Staten Island and perceived likelihood of tick encounter were ordered on a Likert scale and scored out of five, with five being the most severe or most likely. Tick check frequency was converted into a binomial variable and analyzed using a generalized linear model. Model fit to predict tick check behavior was selected based on the lowest AIC value using MuMIN:dredge in R.

RESULTS

Tick Densities, Temporal, Park and Habitat Associations

I performed 432 drags from 20 May to 12 August 2019, (Clove Lakes: n=168; Conference House: n=134; Willowbrook: n=132). All three drag habitats (maintained grass, leaf litter, and unmaintained herbaceous) were present in Clove Lakes and Willowbrook; however, no leaf litter was present in Conference House sites.

During the sampling period, 10036 ticks were collected across all parks, including 7133 *H. longicornis* (adults: n=489; nymphs: n=2599; larvae: n=4045), 1972 *A. americanum* (adults: n=28; nymph: n=157; larvae: n=1787) and 931 *I. scapularis* (adults: n=0; nymphs: n=85; larvae: n=846). Densities for every life stage across each site are shown in Appendix 3. Conference House, the southern-most park, had the greatest number of ticks, comprising 98.8% of all life stages and 91.5% of all nymphs collected, compared to the other two parks. Thus, Conference House was the most hazardous park for encountering ticks.

Tick phenology was variable by species and life stage (Figure 5). From 27 May to 12 August, *A. americanum* nymph density was highest from mid- to late-June, and larval activity increased in late July, continuing to rise after the conclusion of the study in August. *H. longicornis* nymph density peaked in mid-June, adult density peaked in mid-July, and the larvae emerged in late July, increasing post-collection. The density of *I. scapularis* nymphs was consistent from early June to early July before declining. The larvae began to emerge around mid-June, peaking in activity in mid-July. No adult *I. scapularis* were collected. Since this project encompassed the nymphal peak, nymphal hazard across the parks is recorded moving forward; however, low levels of adults and larvae were still present.

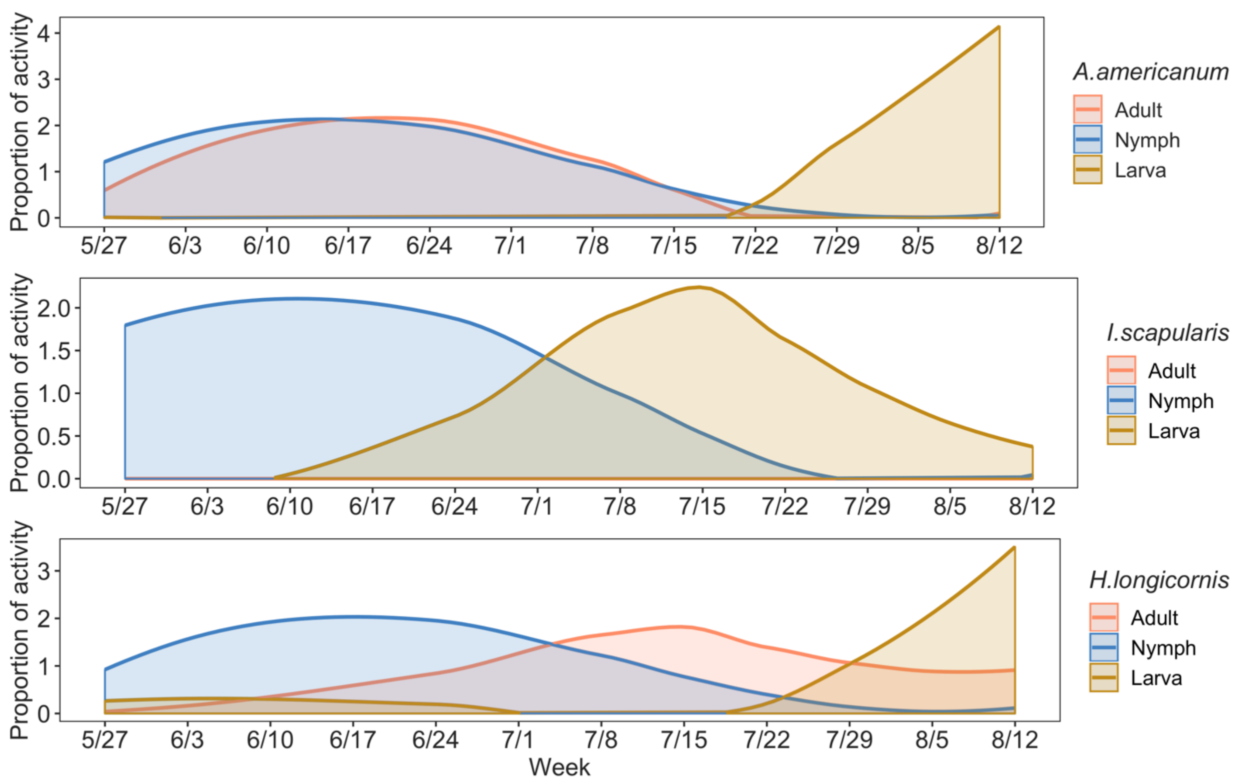

Figure 5. Tick phenology on Staten Island. The proportional activity of each life stage from late-May to mid-August for *A. americanum, I. scapularis* and *H. longicornis* are shown.

Density Comparisons Across Park, Site, and Drag Habitat

Nymph density was the highest for all species in Conference House Park and density comparisons were performed using a Kruskal-Wallis test and post-hoc Dunn's test (Figure 6). *A. americanum* nymphs were in greater densities within Conference House compared to Clove Lakes ($p<0.001$) and Willowbrook ($p<0.0001$), but there was no difference between Clove Lakes and Willowbrook ($p=0.374$). Similarly, more *I. scapularis* were in Conference House park compared to Clove Lakes ($p<0.001$) and Willowbrook ($p<0.001$), but densities were the same between Clove Lakes and Willowbrook ($p=0.368$). *H. longicornis* was limited to Conference House. Within Conference House, there were more *H. longicornis* than *I. scapularis* and *A. americanum* ($p<0.0001$) and more *A. americanum* compared to *I. scapularis* ($p<0.002$). In Clove Lakes, *I. scapularis* density was greater than *A. americanum* ($p=0.03$), but in Willowbrook, density differences were marginal ($p=0.076$). Tick density comparisons are detailed in Table 3.

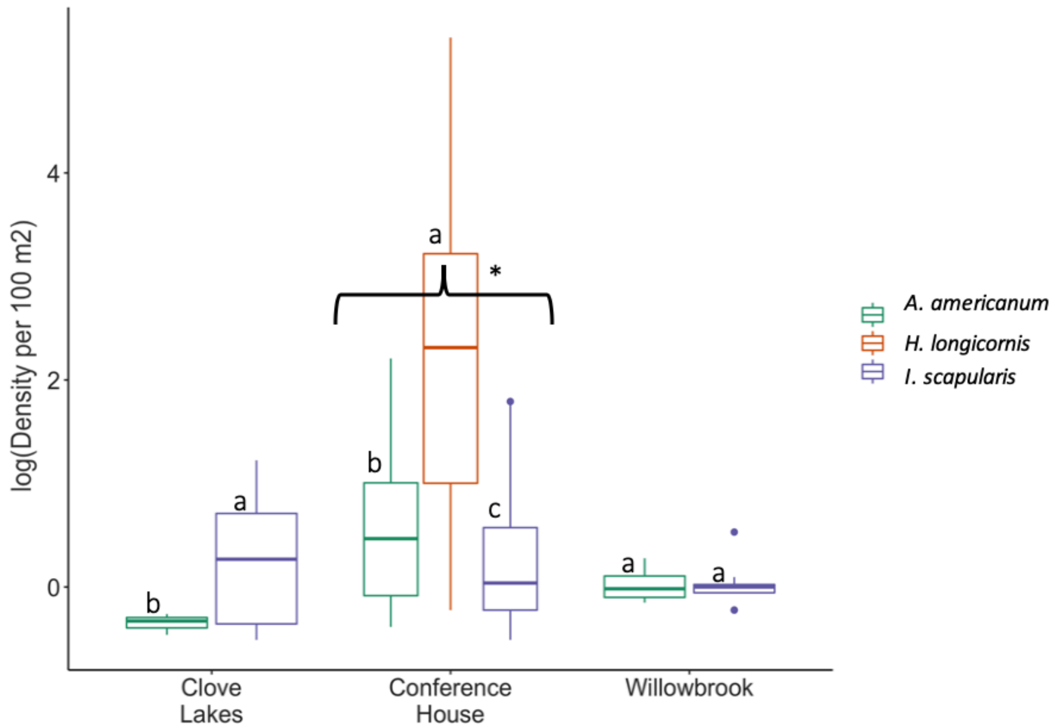

Figure 6. Log densities of nymphs per 100 m^2 by park. Letters indicate within park significance and the asterisk indicates the highest density of every species was within Conference House.

Table 6. Nymphal ticks by park. Total counts (n) and density per 100 m^2 (d) are shown.

Park	Total Distance (m^2)	*A. americanum* n (d)	*I. scapularis* n (d)	*H. longicornis* n (d)
Clove Lakes	16166	3 (0.02) ^{a,a}	17 (0.1) ^{b,a}	0 ^{a,a}
Conference House	14809	150 (1) ^{a,b}	59(0.4) ^{b,b}	2599 (17.5) ^{c,b}
Willowbrook	12485	4 (0.03) ^{ab,a}	9 (0.07) ^{b,a}	0 ^{a,a}

First letter indicates within row significance and second letter shows column significance at α=0.05.

Total tick density was highest in unmaintained herbaceous habitats (Figure 7; Table 7). *H. longicornis* was collected more in unmaintained herbaceous compared to maintained grass ($p<0.0001$) and more in maintained grass compared to leaf litter ($p=0.036$ and $p<0.001$, respectively). Similarly, more *A. americanum* were in unmaintained herbaceous habitats compared to maintained grass ($p<0.0001$) and leaf litter (p<0001). There was no difference in *A. americanum* counts between leaf litter and maintained grass ($p=0.336$) *I. scapularis* was in higher densities in leaf litter ($p=0.008$) and unmaintained herbaceous ($p<0.001$), compared to maintained grass. There was no difference between unmaintained herbaceous compared to leaf litter ($p=0.1$). Nymphal density within habitats in each park are presented in Appendix 4.

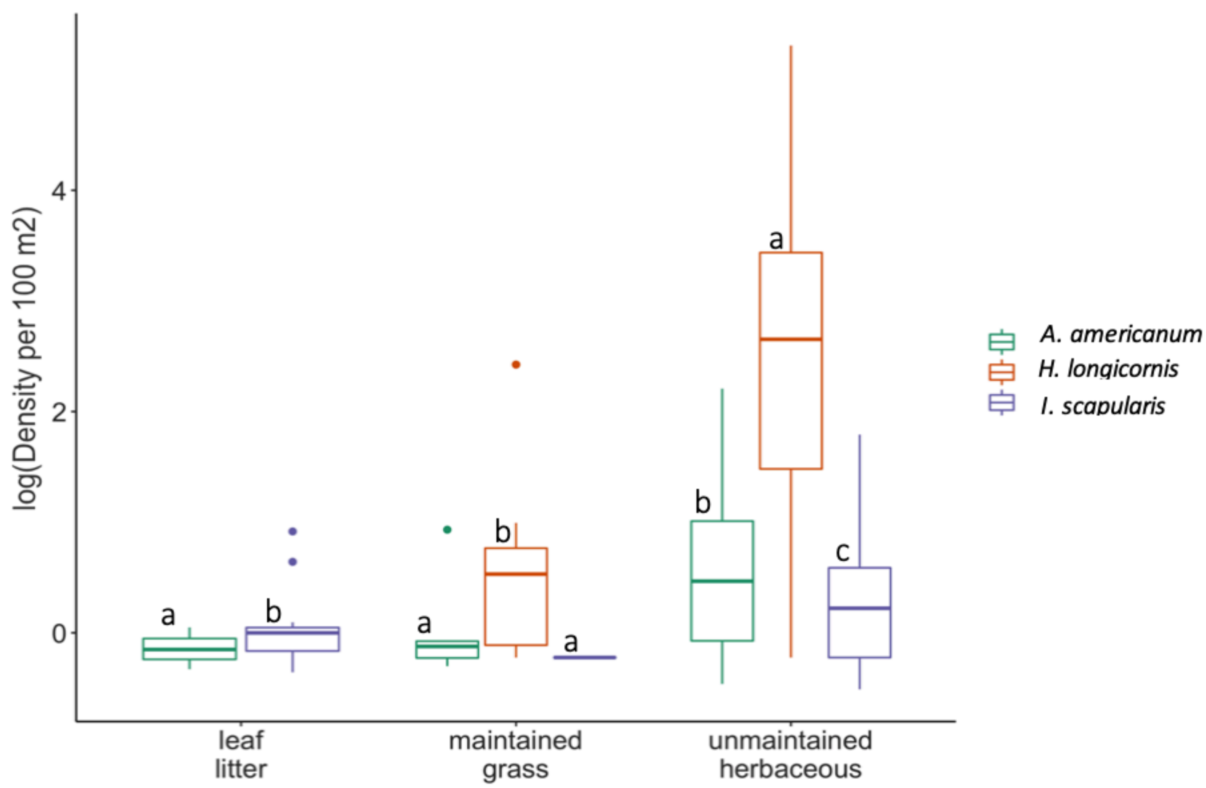

Figure 7. Log density of nymphs per 100 m^2 by habitat. Letters indicate within habitat significance by species. Across habitat significance differs by species and is not shown.

Table 7. Nymph abundance by habitat. Shown are the total counts (n) and nymphal density per 100 m^2 (d) in each habitat.

Habitat	Total Distance (m^2)	*A. americanum* n (d)	*I. scapularis* n (d)	*H. longicornis* n (d)
Leaf Litter	10588	3(0.03) ^{a,a}	16 (0.15) ^{b,a}	0^a
Maintained Grass	10478	8 (0.08) ^{a,a}	1 (<0.001) ^{a,b}	43 (0.4) ^{b,b}
Unmaintained Herbaceous	22394	146 (0.65) ^{a,b}	68 (3) ^{b,a}	2556 (11.4) ^{c,c}

First letter indicates within row significance and second letter shows column significance at α==0.05.

Tick density was highest in trails compared to open spaces with and without edges (p<0.001) for all species (Figure 8). Within trails, there were more *H. longicornis* than *A. americanum* (p<0.0001) and *I. scapularis* (p<0.0001). The difference between *A. americanum* and *I. scapularis* was marginally significant (p=0.069). Within edges, there was no difference between species (p>0.1). There were more *H. longicornis* in open spaces without edges compared to *A. americanum* (p=0.014) and *I. scapularis* (p=0.0002). There was no difference between *I. scapularis* and *A. americanum* (p=0.093). Comparisons are shown in Table 8. Counts and density by site type across parks are shown in Appendix 5.

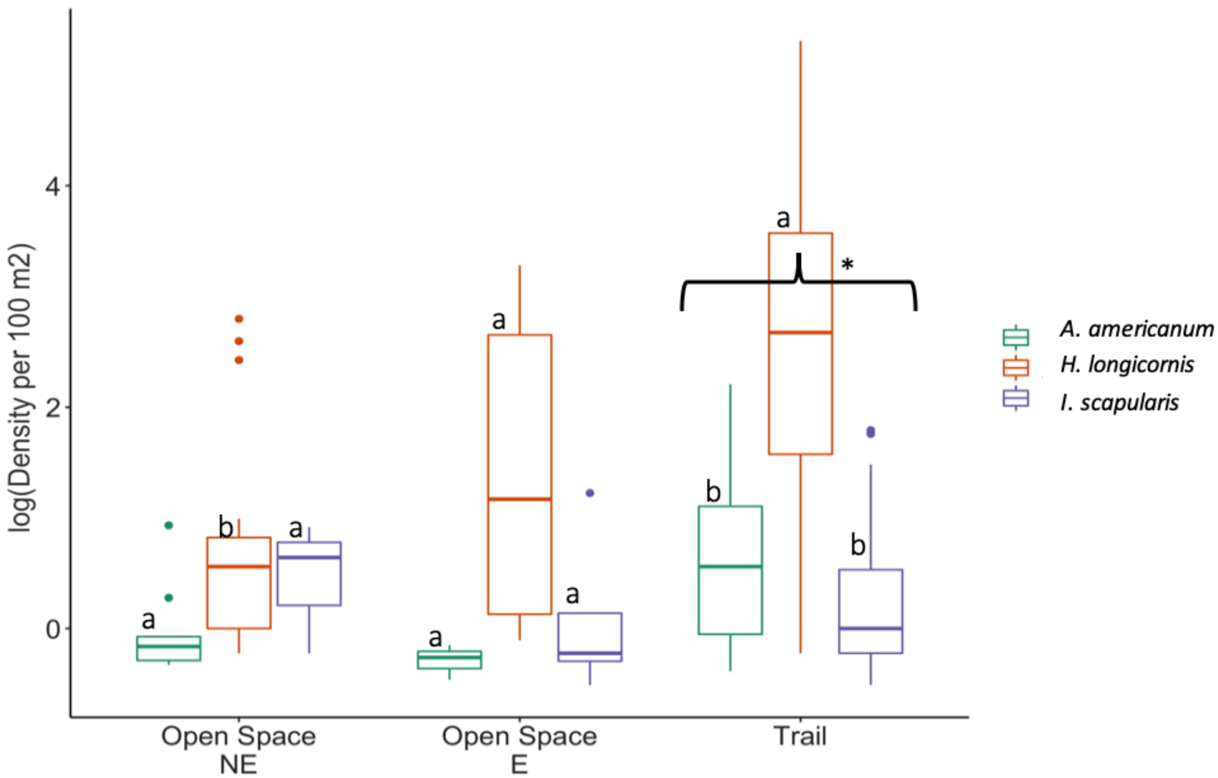

Figure 8. Log nymph density per 100 m^2 by site type. Open spaces had either an edge (E) or no edge (NE). Letters indicate within site significance by species. The asterisk indicates that species density was highest within trails for all species.

Table 8. Nymph abundance by site type. Total counts (n) and nymph density per 100 m^2 (d) is shown in each site type. Open spaces had either an edge (E) or no edge (NE).

Site Type	Total Distance (m^2)	*A. americanum* n (d)	*I. scapularis* n (d)	*H. longicornis* n (d)
Trail	8794	143 (1.63) ^{a,a}	70 (0.79) ^{a,a}	2450 (27.86) ^{b,a}
Open Site E	13410	3(0.02) ^{a,b}	7 (0.05) ^{a,b}	70 (0.52) ^{a,b}
Open Site NE	21256	11(0.05) ^{a,b}	8 (0.04) ^{a,b}	79 (0.37) ^{b,b}

First letter indicates within row significance and second letter shows column significance when alpha=0.05.

Modeling Tick Counts

For all models, maintained grass was the reference variable for drag habitat, Clove Lakes for park, and open space without edges for site type. Back-transformed model coefficients were calculated to determine the ratio of tick counts between variables. Pairwise comparisons were generated using emmeans: pairs, and with type= "response", the mean number of predicted ticks per 100 m^2 was calculated for all model variables. Table 9 provides the relative abundance and predicted tick density per 100 m^2 for each modeled variable and species.

The factors that best influenced nymphal counts varied by species. *A. americanum* was analyzed with the park, drag habitat, and site type coefficients. The mean number of predicted ticks per 100 m^2 was 37.4 in Conference House, 1.9 in Willowbrook, and 1.1 in Clove Lakes. Willowbrook and Clove Lake densities were not significantly different. The mean predicted *A. americanum* counts per 100 m^2 were highest in unmaintained herbaceous (n=8.9), followed by leaf litter (n=6), and then maintained grass (n=1.5); however, leaf litter and maintained grass were not statistically different. The mean number of predicted *A. americanum* per 100 m^2 was 7.5 along trails, 6.5 along non-edge open spaces, and 1.7 along open space edges, but there was no difference in the model between site type and the reference variable (non-edge open spaces). However, at the edge of open spaces there were less *A. americanum* than trails (p=0.03).

I. scapularis presence and abundance was explained best by park and drag habitat. The mean number of predicted nymphs per 100 m^2 in each park was 28.6 in Conference House, 6.5 in Clove Lakes, and 5.7 in Willowbrook (Table 9). There was no difference between Clove Lakes and Willowbrook (p=0.8). Within drag habitat, the number of predicted *I. scapularis* per 100 m^2 was 35.9 in leaf litter, 25.6 in unmaintained herbaceous, and 1.1 in maintained grass. Both leaf litter and unmaintained herbaceous had higher densities compared to grass ($p<0.01$). Site type was not modeled for *I. scapularis* since ticks were mainly found in trails.

H. longicornis counts were best described by site type differences and drag habitat. Park was removed from the model since *H. longicornis* was only found in Conference House. Within drag habitats, there were 124 mean predicted ticks per 100 m^2 in maintained grass compared to 1278 ticks per 100 m^2 in unmaintained herbaceous, and this difference was significant ($p=0.003$). The mean number of predicted *H. longicornis* per meter was 827 along trails, 355 in non-edge open spaces, and 216 along open space edges. Mean predicted tick densities in trails and open spaces with edges were not significantly different to open spaces without; however, trails had more ticks compared to open spaces with edges ($p=0.008$).

Table 9. Negative binomial model summary of each coefficient for each species. The p-value compares each level to the reference category (NA). Open spaces had either an edge (E) or no edge (NE).

Variable	Category	Relative Abundance; 95% CI	P-value	Number of Predicted Ticks per 100m^2; 95% CI
A. americanum				
Intercept		0.01; (0.0059, 0.0167)	< 2e-16	NA
Park	Clove Lakes	1	NA	1.13; (0.33, 3.83)
	Conference House	33.1;(8.1159, 134.95)	1.06e-06	37.4; (19.78, 78.19)
	Willowbrook	1.69; (0.3.6527, 7.824)	0.5018	1.91; (0.66, 5.51)
Site Type	Open Space NE	1	NA	6.5; (2.49, 17.2)
	Open Space E	0.25; (0.044, 1.44)	0.55744	1.65; (0.438, 6.20)
	Trail	1.15; (0.298, 4.43)	0.25361	7.50; (3.37, 16.6)
Habitat	Maintained Grass	1	NA	1.49 (0.377, 5.96)
	Unmaintained Herbaceous	5.97; (1.2858, 2.7717)	0.00266	8.98; (3.95, 20.39)
	Leaf Litter	4; (0.5153, 31.0526)	0.1849	6.0; (1.67, 21.65)
I. scapularis				
Intercept		0.0006; (0, 0.0005)	< 2e-16	NA
Park	Clove Lakes	1	NA	6.48; (2.65, 15.9)
	Conference House	4.412; (1.7898,10.876)	0.00126	28.61; (12.69, 64.5)
	Willowbrook	0.885; (0.339, 2.309)	0.80301	5.74; (2.10, 15.7)
Habitat	Maintained Grass	1	NA	1.16 (0.155, 8.65)
	Unmaintained Herbaceous	22.059; (2.9541, 164.728)	0.00256	25.57; (15.396, 42.45)
	Leaf Litter	31; (3.5573, 270.219)	0.00188	35.93; (18.273, 70.65)
H. longicornis				
Intercept		0.010; (0.0059, 0.0167)		NA
Site Type	Open Space NE	1	NA	355; (165.8, 758)
	Open Space E	0.61; (0.1159, 3.1955)	0.55744	216; (69.6, 670)
	Trail	2.33; (0.5449, 9.984)	0.25361	827; (370.1, 292)
Habitat	Maintained Grass	1	NA	124; (40.4, 382)
	Unmaintained Herbaceous	10.28 (2.2478, 47.0447)	0.00266	1278; (730, 2242)

Pathogen Testing

All *H. longicornis* tested were negative for all pathogens tested: *A. phagocytophilum, Babesia microti, Bartonella spp., B. burgdorferi, B. mayonii, B. miyamotoi, E. canis, E.*

chaffeensis, E. ewingii, Heartland virus, *Mycoplasma haemocanis,* Powassan virus, *Rickettsia* spotted fever group, *Rickettsia spp.,* severe fever with thrombocytopenia syndrome virus, and *Theileria orientalis.*

Tick Hazard Summary

Total nymphal tick hazard was between early June to early July, and species hazard was influenced by park, habitat, and site type. *I. scapularis* and *A. americanum* were collected in highest densities in Conference House Park, and all *H. longicornis* nymphs were restricted to Conference House. All ticks were predominantly in unmaintained herbaceous and trails. When outside of Conference House, *I. scapularis* was also present in leaf litter. Importantly, at least one nymph of each species was found in maintained grass, and the most ticks in maintained grass were in Conference House Park. Therefore, a low risk for tick exposure still exists in areas of maintained grass such as mowed lawns.

Human and Tick Interaction

From late May to mid-August, 5910 individuals entered the parks (Clove Lakes: n=2773; Conference House: n=1162; Willowbrook: n=1975), of which 3214 were men and 2632 were women ($p<0.0001$), when gender was visible. A two-sample proportion test showed that fewer people visited Conference House compared to Clove Lakes ($p< 0.0001$) and Willowbrook ($p< 0.0001$), decreasing the overall risk of tick exposure for most visitors. There were significantly more adults in parks compared to children ($p<0.0001$), teens ($p<0.0001$), and seniors ($p<0.0001$). Table 10 compares gender and age group counts in each park. Since 98.8% of ticks were in Conference House, analysis for exposure risk is focused on this park.

Table 10. Number of park visitors by age group and gender. The total number (n) out of the total (%) from each park.

Park		Gender		Age Group			
		Male	Female	Child	Teen	Adult	Senior
Clove Lakes	n (%)	1563 ^{a,a} (56.8)	1191 ^{b,a} (43.2)	200 ^{a,a} (7.2)	207 ^{a,a} (7.4)	1877 ^{b,a} (67.7)	490 ^{c,a} (17.7)
Conference House	n (%)	648 ^{a,b} (55)	529 ^{b,b} (44.9)	288 ^{a,a} (24.3)	151 ^{b,b} (12.7)	582 ^{c,b} (49)	166 ^{d,b} (14)
Willowbrook	n (%)	1003 ^{a,c} (52.4)	912 ^{b,c} (47.6)	402 ^{a,b} (20.3)	174 ^{b,b} (8.8)	1187 ^{c,c} (60)	214 ^{b,b} (10.8)
Total		3214 ^{a}	2632 ^{b}	890 ^{a}	532 ^{b}	3646 ^{c}	870 ^{b}

The first letter represents cross row comparison, the second letter is within-column comparisons with alpha=0.05.

Visitation to hazardous tick sites and habitats varied by gender. Within Conference House, tick hazard areas were trails, unmaintained herbaceous, and maintained grass habitats. More men entered trails compared to females ($p<0.0001$; Table 11). Likewise, a higher proportion of men than women entered unmaintained herbaceous habitats ($p<0.0001$). In contrast, men and women equally entered maintained grass ($p=0.87$), maintained grass-unmaintained herbaceous ($p=0.72$), and built/bare earth- unmaintained herbaceous habitats ($p=0.39$). Data from Clove Lakes and Willowbrook is presented in Appendix 6.

Table 11. Presence of men and women in Conference House site types and habitats. The counts (n) and within-gender proportions (%) are shown in each site type and hazardous habitat (non-hazardous habitats excluded). Habitats include built/ bare earth (BBE), maintained grass (MG), and unmaintained herbaceous (UH).

Gender		Site Type		Hazardous Habitat				
		Open Space	Trail	BBE-MG	MG	MG-UH	UH	BBE UH
Female	n	$451^{a,a}$	$78^{b,a}$	$108^{a,a}$	$83^{a,a}$	$9^{bd,a}$	$83^{c,a}$	$7^{d,a}$
	%	$(85.3)^{a,a}$	$(14.7)^{b,a}$	$(20.4)^{a,a}$	$(15.7)^{a,a}$	$(1.7)^{bd,a}$	$(15.7)^{c,a}$	$(1.3)^{d,a}$
Male	n	$474^{a,a}$	$174^{b,b}$	$142^{a,b}$	$105^{ac,a}$	$14^{bd,a}$	$188^{c,b}$	$14^{dd,a}$
	%	$(73.1)^{a,b}$	$(26.9)^{b,b}$	$(21.9)^{a,a}$	$(16.2)^{ac,a}$	$(2.1)^{bd,a}$	$(29)^{c,b}$	$(2.2)^{dd,a}$

The first letter represents cross row comparison, the second letter is within-column comparisons with alpha=0.05.

Visitation to hazardous locations varied by age group. Overall, all age groups entered open spaces more often than trails (Table 12). Even though adults comprised the majority of Conference House park visitors (n=582; 49%) and entered trails (n=144; 24.7%) and unmaintained herbaceous habitats more frequently (n=149; 25.6%), seniors disproportionately entered trails and unmaintained herbaceous habitats compared to other age groups ($p<0.05$). While maintained grass was a less tick hazardous habitat than unmaintained herbaceous areas, it still posed a threat to park visitors who may assume ticks are not in manicured lawn spaces. Appendix 7 presents counts and proportions of visitors in all three parks and all site type and habitat types.

Table 12. Age group visitation to Conference House site types and hazardous habitats. The counts (n) and within-group proportions (%) are shown in each site type and hazardous habitat (non-hazardous habitat excluded). Habitats include built/ bare earth (BBE), maintained grass (MG), and unmaintained herbaceous (UH).

Age Group		Site Type		Hazardous Habitat				
		Open Space	Trail	BBE-MG	MG	MG-UH	UH	BBE-UH
Child	n	268 ^{a,a}	20 ^{b,a}	46 ^{c,a}	28 ^{bc,a}	0	22 ^{a,a}	1 $^{ab, a}$
	%	(93.1) ^{a,a}	(6.9) ^{b,a}	(16) ^{c,a}	(9.7) ^{bc,a}		(7.6) ^{a,a}	(<1) ^{ab,a}
Teen	n	121 ^{a,b}	30 ^{b,a}	35 $^{b, a}$	34 ^{b,a}	2 ^{a,ab}	34 ^{ab,a}	0
	%	(80.1) ^{a,b}	(19.9) ^{b,b}	(23.2) ^{b,ab}	(22.5) ^{b,b}	(1.3) ^{a,a}	(22.5) ^{ab,b}	
Adult	n	438 ^{a,c}	144 ^{b,b}	132 ^{c,b}	102 ^{bc,b}	18 ^{a,b}	149 ^{b,c}	13 ^{a,a}
	%	(75.3) ^{a,b}	(24.7) ^{b,b}	(22.7) ^{c,b}	(17.5) ^{bc,b}	(3.1) ^{a,a}	(25.6) ^{b,b}	(2.2) ^{a,ab}
Senior	n	108 ^{a,d}	58 ^{b,c}	36 ^{c,a}	24 ^{bc,a}	3 $^{a, a}$	66 ^{c,b}	8 ^{ab,a}
	%	(65) ^{a}	(34.9) ^{c}	(21.7) ^{c,ab}	(14.5) ^{bc,ab}	(1.8) ^{a,a}	(39.8) ^{c,c}	(4.8) ^{ab,b}

First letter indicates within row significance and second letter shows column significance at α==0.05.

Certain activities may put individuals at risk if they are performed in hazardous tick habitats or if engaging in the activity exposes visitors to hazardous habitats for longer periods of time. While the majority of people entering the parks stayed on built environments, individuals tended to spend longer times on maintained grass when it was available. Likewise, the fewest number of people entered leaf litter and unmaintained herbaceous habitats, and individuals stayed there for short periods of time (Appendix 8). In Conference House, most people who were exposed to maintained grass were sitting (n=56), walking (n=53), or picnicking (n=34). Picnickers were exposed to the habitat for an average of 16.4 min followed by sitters for an average of 14.1 min (Appendix 9). Individuals going into unmaintained herbaceous habitats were park employees working for an average of three minutes, followed by walkers who spent an average of 1.7 min. Those who entered unmaintained herbaceous trails were walking (n=165), biking (n=59), or jogging/running (n=24) into trails; however, the distance travelled, speed of movement, and time spent in this habitat is unknown.

There was little variation in duration spent in hazardous habitats by age or gender (Table 13). In Conference House, all age groups, men, and women spent equal time in maintained grass, and they spent the most time in grass compared to other hazardous habitats ($p<0.05$). Likewise, all groups spent the same amount of time in unmaintained herbaceous habitats; however, this excludes trail information.

Table 13. Time spent in hazardous habitats in Conference House by age group and gender. Minutes depicted represent the estimated marginal mean minutes. Habitats include built/ bare earth (BBE), maintained grass (MG), and unmaintained herbaceous (UH).

Age Group/ Gender	Hazardous Habitat									
	BBE-MG		MG		MG-UH		UH		UH-BBE	
	Time (min)	SE	Time (min)	SE	Time (min)	SE	Time (min)	SE	Time (min)	SE
Child	1.3 ^{a,a}	1.21	13.4 ^{b,a}	1.71	NA	NA	1.5 ^{a,a}	1.21	0.0 ^{a,a}	3.65
Teen	1.2 ^{a,a}	1.21	8.5 ^{b,a}	1.21	0.0 ^{a,a}	1.71	0.0 ^{a,a}	1.21	NA	NA
Adult	1.6 ^{a,a}	1.21	8.7 ^{b,a}	1.21	2.7 ^{a,a}	1.21	1.4 ^{a,a}	1.21	0.6 ^{a,a}	3.17
Senior	1.1 ^{a,a}	1.21	9.1 ^{b,a}	1.21	0.1 ^{a,a}	1.21	0.3 ^{a,a}	1.21	0.1 ^{a,a}	2.64
Male	1.38 ^{a,a}	0.861	8.25 ^{b,a}	0.994	0.696 ^{a,a}	1.21	0.375 ^{a,a}	0.861	0.57 ^{a,a}	1.218
Female	1.23 ^{a,a}	0.861	10.34 ^{b,a}	0.861	1.44 ^{a,a}	0.994	1.667 ^{a,a}	0.994	0.36 ^{a,a}	0.994

First letter indicates within row significance and second letter shows column significance at α==0.05.

Risk Summary

Overall, the least number of people visited the most hazardous park: Conference House. Of those who went to Conference House, men and adults visited more frequently overall. Even though more men entered trails and unmaintained herbaceous areas, exposure time in hazardous habitats was equal for men and women. While adults were the most abundant visitors in all habitat types, seniors were disproportionately visiting unmaintained herbaceous habitats and trails compared to other age groups. All groups were exposed to unmaintained herbaceous habitats for the same amount of time, yet exposure time on trails could not be captured. Moreover, all park visitors spent the most time on maintained grass. As a whole, all park attendees visited hazardous habitats and locations to some extent, indicating varying degrees of exposure risk for everyone at the park.

Knowledge, Attitudes, Demographics, and Experience Influence Behavior

Demographics and Visitor Experience

I collected 190 surveys (Clove Lakes: n=65; Willowbrook: n=61, Conference House: n=64), and survey responses are displayed in Appendix 10. Of the 232 park visitors who were asked to participate in the survey, 42 refused, resulting in an 18% refusal rate due to not speaking English (29%), refusing to participate (39%), or having an excuse (33%). Among the refusals, 52% were male, and 46% of the refusals were observed to be between 50-70 years old. Respondents who agreed to participate were predominately residents of Staten Island (n=176; 93%), male (n=109; 57.4%; p= 0.0501), White/Caucasian (n=112; 58.9%), and non-Hispanic or Latino (n=153; 80.5%). The age range of respondents was from 18-82 with a median age of 50 and a mean age of 49.4. Education ranged from having a high school degree or less (n=41; 21.6%) to having a graduate degree (n=24; 12.6%); however, most attended some college or received an associate degree (n=71; 37.4%).

Most visitors frequented the parks to engage in a variety of activities, and they reported overall high levels of general happiness. Thirty-six percent (n=69) of respondents reported visiting the parks daily, and those who did not would attend at least weekly (n=54; 28.4%). Walking/running (n=102; 53.7%), dog walking (n=39; 20.5%), and relaxing (n=28; 14.7%) were the top activities enjoyed by respondents. On a scale of 1-10 (1 being "not at all happy" and 10 being "extremely happy"), 74% (n=141) of respondents reported their overall happiness being between 8-10, and 90% agreed to strongly agreed that they were happy while in the park.

The majority of respondents (60%; n=114) had some level of past tick exposure. Sixty percent of visitors (n=114) reported seeing a tick before, of which 53.5% (n=61) reported finding ticks on either themselves or a household member, and 54.4% (n=61) had found ticks on a pet. Forty-four percent of respondents (n=84) knew someone with Lyme disease, of which 30.9% (n=58) knew one individual and 12.4% (n=23) knew two people. Eighteen percent (n=19) reported having someone in the household with Lyme disease. Prior experience with ticks was not associated with age, gender, education, park, perceived level of severity, or perceived probability of tick encounter ($p>0.05$).

Knowledge and Attitudes

Park visitors were moderately to highly knowledgeable about tick phenotype but less knowledgeable about disease biology. Of those who claimed to have seen a tick before, most could distinguish ticks from non-ticks from a sample of eight arthropods (Figure 4). Sixty-four percent (n=72) correctly identified the *D. variabilis* adult, 38.1% (n=43) identified the *A. americanum* adult, and 26.5% (n=30) recognized the *I. scapularis* adult as ticks. However, only 3.5% (n=4) were able to tell that the *I. scapularis* nymph was a tick. Importantly, respondents were able to identify ticks more often when they had prior experience with ticks ($p=0.04$). Knowledge of tick phenotype was not affected by age, education, gender, park, perceived severity, and perceived probability of tick encounter ($p>0.05$). Additionally, most did not know how ticks become infected with the Lyme bacterium (n=78; 63.7%), and 22.6% (n=24) incorrectly assumed infection was from feeding on deer. Only 8.4% (n=16) knew that infection was caused by feeding on infected mice, and 8.9% (n=17) claimed it was due to feeding on infected animals in general.

Regarding tick habitat, most identified parks as the main source for tick exposure (n=82; 43.2%), followed by woods (n=52; 27.4%) and grass (n=32; 16.8%). Moreover, 12.6% connected tick exposure to the presence of deer (n=24). People were more likely to know about tick habitat if they had more experience with ticks ($p<0.001$) and a higher perceived probability of tick encounter ($p=0.032$), but knowing tick habitat did not influence whether park visitors avoided tick habitat ($p=0.392$). Knowledge of tick habitat was not affected by education, gender, age, or perceived severity ($p>0.05$). Visitors in Conference House knew marginally more about tick habitat compared to visitors in Willowbrook ($p=0.059$).

There were varying responses regarding the reduction of Lyme disease on Staten Island, and visitors could respond with multiple answers. Most believed that spraying pesticides (n=63; 34.9%), educating the public (n=55; 29.6%), and reducing or controlling deer (n=33; 17.7%) would control the disease. Fewer people reported personal protection measures (n=15; 8.1%), vegetation management (n=12; 6.5%), mice control (n=6; 3.2%) and general tick reduction (n=6; 3.2%). A small proportion (n=19; 10.2%) did not know what could be done, and 4.3% (n=8) said that nothing could reduce Lyme disease.

Knowledge of tick prevention measures was limited, and respondents could provide multiple answers. Thirty-three individuals (17.4%) did not know any prevention measures. Of the respondents who were aware of prevention methods, they knew a median of two and a mean of 2.6 measures. Sixty-two percent (n=117) knew about insect repellent, 40% (n=76) about wearing long sleeves, 35.8% (n=68) knew to avoid tick habitat, 24.7% (n=47) were familiar with tick checks, and 23.2% (n=44) reported knowing about tucking pants into socks or wearing long socks. Fewer people reported knowing about wearing light colored clothing (n=15; 7.9%) and showering after being outdoors (n=10; 5.3%). The number of known preventative measures was not influenced by age, gender, park, or past experience ($p>0.05$). However, graduates knew more methods compared to individuals who had a high school degree or less ($p=0.018$). Knowledge of prevention measures increased with those who had a high perceived probability of tick encounter ($p=0.0196$) and those who knew more about tick ID ($p=0.007$). Perceived severity was marginally associated with knowing preventative behaviors ($p=0.073$).

Perceptions of tick-borne disease severity were moderate to high. Most respondents believed tick-borne diseases were either extremely serious or very serious (n=80; 42.1%), while 15.8% (n=30) believed they were not at all serious or slightly serious. However, 20% were unsure about the status of tick-borne diseases on Staten Island (n=38). Visitors from Conference House believed tick-borne diseases were more serious than visitors from Clove Lakes ($p=0.02$), and those who had a greater perception of severity were more likely to change their activities for fear of tick exposure ($p=0.043$). Likewise, those who had a higher perceived probability of tick encounter had a higher perception of severity ($p<0.001$). Perceived level of severity was not influenced by age group, gender, education, previous experience, or knowledge of tick ID or habitat ($p>0.05$).

Perceived probability of tick encounter was very low. Interestingly, while most park visitors claimed the parks were the main locations for tick exposure, the majority believed it was unlikely or very unlikely that they or a family member would encounter a tick (n=98; 51.9%)

compared to those that believed it was somewhat or very likely (n=46; 24.4%; $p < 0.0001$). However, perceived probability of tick encounter was higher for those who believed tick-borne diseases were very serious, compared to those who thought they were only slightly serious ($p=0.03$). Prior experience with ticks and knowledge of tick phenotype had a marginally significant effect on perceived likelihood of tick encounter ($p=0.065$ and $p=0.052$, respectively). There was no association with park, age, education, gender, or knowledge of tick habitat on probability of tick encounter ($p>0.05$).

Practices

Respondents who practiced tick prevention methods practiced a median of two methods. Most practiced no methods (32.8%; n=62), while 30.7% practiced one (n=58; 30.7%) and 19% practiced two (n=36) (Table 14). The most commonly used prevention methods were avoiding tick habitat (n=58; 30.7%), using repellent (n=54; 28.5%), wearing long sleeves (n=49; 25.9%), and conducting tick checks (n=34; 18%). Fewer people reported tucking pants into socks or wearing long socks (n=26; 13.8%), wearing light colored clothing (n=7; 3.7%), or showering after being outdoors (n=8; 4%; Figure 9).

Table 14. The number of tick-preventative methods practiced by park visitors. This shows the count and percentage of people who practiced a certain number of methods.

# of Methods	Number of Individuals n (%)
None	62 (32.8)
One	58 (30.7)
Two	36 (19)
Three	20 (10.6)
Four	10 (5.3)
Five	2 (1.1)
Six	0
Seven	1 (0.5)

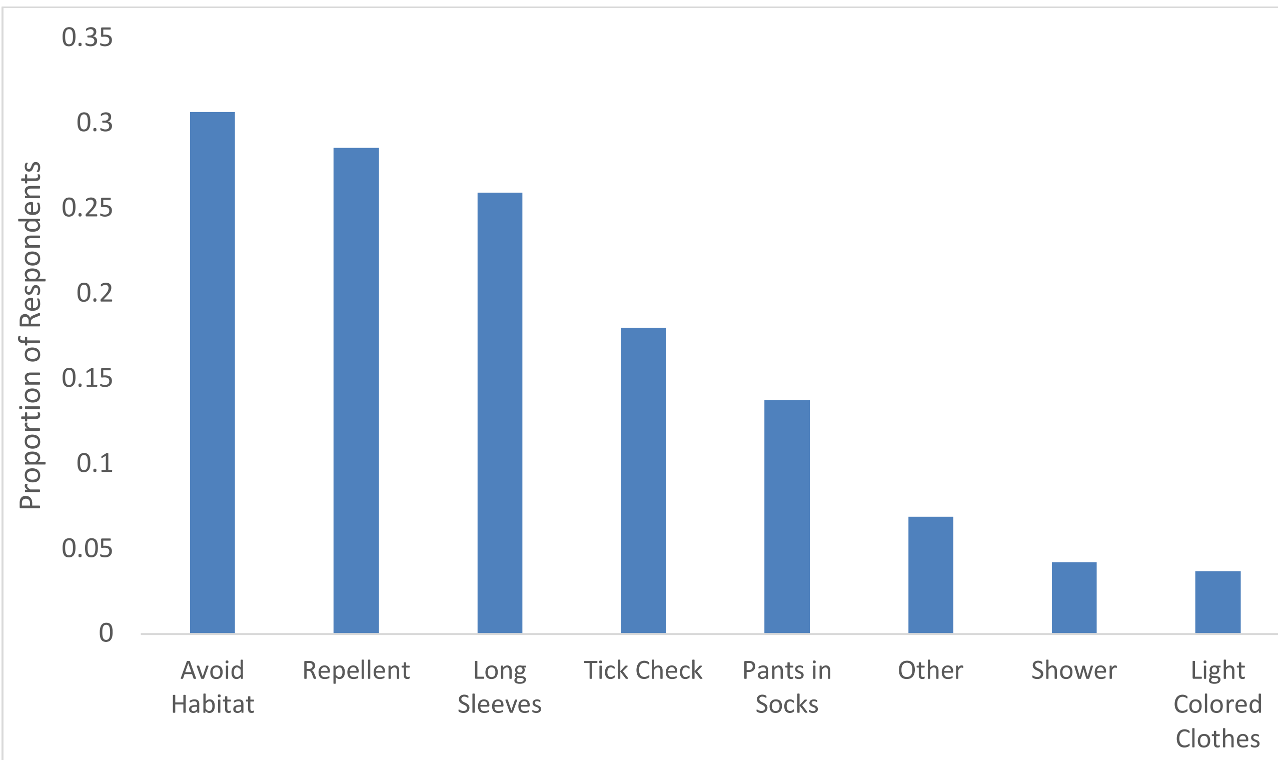

Figure 9. Frequency of tick prevention methods practiced. Most respondents practiced avoiding tick habitat, using repellent, wearing long sleeves, and practicing tick checks.

Checking the body for ticks after being outdoors (and removing ticks if found) remains one of the best ways to decrease the chances of obtaining a tick-borne disease. The majority of people (n=99; 58%) reported checking for ticks either sometimes or always, while 42% (n=79) reported never checking for ticks. Those who never checked for ticks believed they were not in an area with ticks (24%; n=46), they reported laziness (12%; n=23), forgot to check (12%, n=22), never had experience with ticks (10%, n=19), or did not think about it at the time (10%; n=19).

Results from the generalized linear model (Table 15) showed that tick check behavior could be best predicted by the number of tick prevention methods known, the perceived probability of tick encounter, and knowledge of tick habitat. With each unit increase in the known number of prevention methods, the odds of checking for ticks increased by a factor of 1.9. The odds of checking for ticks was 3.7x more when increasing from no known methods to two methods. Likewise, with each unit increase in the perceived probability of encountering a tick, the odds of checking for ticks increased by 1.6. The odds of a park visitor checking for ticks who perceived their risk for tick encounter as “extremely likely” was 6.9x higher than a person who perceived their risk for tick encounter as “very unlikely”. As individuals became more aware of tick habitat, the odds that they would check for ticks decreased by 0.5 for each unit increase in habitat knowledge. However, this is a marginally significant trend (p=0.067).

Table 15. Generalized linear model for predicting tick checks. The odds of checking for ticks was obtained by exponentiating the estimate.

Predictor	Estimate	SE	P-value	Performing Tick Check Odds Ratio
Intercept	-0.7419	0.5881	0.2712	
Prevention Methods Known	0.6605	0.2235	0.00312	1.9
Probability of Tick Encounter	0.4845	0.1711	0.00464	1.6
Knowledge of Tick Habitat	-0.6434	0.3508	0.06664	0.5

Discussion

Visiting green spaces is important for human mental health and wellbeing, especially in cities. However, visiting public parks could put individuals at risk for encountering ticks, and subsequently, tick-borne disease exposure. Because Lyme disease is the most prevalent vector-borne disease in the United States, and is particularly an issue in the Northeast, I sought to understand the relationship between tick density in public parks and park usage. Few studies exist that track human movement in public parks into hazardous tick locations, and this information can be beneficial in promoting tick awareness. I also sought to learn how knowledge, experiences, and attitudes may influence behavior, elucidating the gaps in the public's knowledge and response to tick exposure. In the first study of its kind conducted to date, from 20 May to 19 August 2019, I sampled for ticks, observed park visitor behavior, and administered surveys to 190 individuals in three parks on Staten Island: Clove Lakes, Conference House, and Willowbrook.

Conference House Park contained 98.8% of all collected ticks and was, therefore, the most hazardous park to encounter ticks. However, fewer people visited Conference House compared to the other two surveyed parks, and most stayed in open spaces, limiting the risk for exposure. Adults and men comprised the majority of Conference House visitors, and they entered high tick hazard locations most frequently. However, seniors were disproportionately affected since more seniors opted to visit hazardous areas compared to any other age group. Furthermore, at least one of every species was collected in maintained grass (lawn) spaces, and, within Conference House Park, this is where all groups of people were exposed for the most amount of time. Traditional education for Lyme disease vectors has focused on woodland trails and herbaceous habitats, but many individuals may not anticipate tick exposure in manicured lawn spaces. Regardless, the greatest density of ticks remains in trails and unmaintained herbaceous habitats, posing a risk to visitors who use these spaces.

My results are consistent with Goličnik and Ward Thompson (2010) regarding use of open spaces but differ slightly with a study by Evenson et al. which reported that men and younger individuals visited parks the most (Evenson et al. 2016). While studies report that older people tended to disfavor natural landscapes for recreational use and preferred the removal of these habitats (Lyons 1983, Zube et al. 1983, Tahvanainen et al. 2001, Bjerke et al. 2006), these studies employed questionnaires about preference, which may not translate into actual use. As such, I found that seniors and adults visited natural areas the most.

Overall, differences in park use vary considerably and may be influenced by confounding variables such as the location of and ability to access the park, quantity and quality of facilities available, the level of safety, preferences by demographics, and the aesthetic attraction of park spaces. More research is required in the United States on the natural movement of visitors in specific park facilities and habitats in order to determine drivers of park use and subsequent risk for tick exposure.

While information is limited on the relationship between park usage and tick exposure, it is clear that tick distribution and therefore tick exposure is not homogenous across parks (Falco and Fish 1989, Johnson et al. 2017, Simmons et al. 2019, Tufts et al. 2019, VanAcker et al. 2019). In my study, *I. scapularis* ranged from 0.07 nymphs/100 m^2 in Willowbrook to 0.4/100 m^2 in Conference House, and *A. americanum* had a density of 0.02/ 100m^2 in Clove Lakes and 1.0/100m^2 in Conference House. *H. longicornis* density was 17.5/100 m^2 in Conference House. My results were consistent with other studies in the region showing varying levels of *I. scapularis* tick density in high visitor use areas (Falco and Fish 1989, Johnson et al. 2017). While most studies have focused on *I. scapularis*, information about *A. americanum* on Staten Island and the Northeast United States is limited since it began appearing in the southeastern region of New York in 1972 on Long Island in New York City (Good 1972).

Surveys of park visitors were employed in the current study to understand their knowledge, attitudes and practices towards ticks and TBD. Most respondents were generally knowledgeable. However, only 26.5% of respondents could distinguish an *I. scapularis* adult as a tick, and even fewer recognized a nymph (4%). A lack of recognition of ticks, especially nymphs, could lead to greater risk and lower efficacy of personal prevention measures.

Tick prevention methods varied. The most commonly cited prevention method was avoidance of tick habitat, followed by repellent use and wearing long sleeves. Even fewer people practiced tick checks, tucked pants into socks, wore light colors, or showered. These results are similar to those reported by Bayles et al. who found that tick checks, avoiding wooded/grassy areas and using repellent were practiced the most while tucking pants into socks and wearing long sleeves were used less often (Bayles et al. 2013). Alternatively, a study in Connecticut found that most respondents practiced checking for ticks and showered to prevent bites (Butler et al. 2016).

I found that knowing a greater number of tick prevention methods and believing there is a higher probability of tick encounter led people to perform more tick checks. However, knowing about tick habitat decreased their tendency to do tick checks. This is similar to the findings by Donohoe et al. (2018) which found that tick checks were predicted by having more knowledge of tick prevention, having more intent to practice the preventative measures, perceiving a higher risk for TBD exposure, and perceiving that preventative measures were effective against tick bites. However, Butler et al. (2016) found that practicing tick checks was related to self-reported history of disease, and those infected with a TBD were more likely to perform tick checks. Other work in Massachusetts concluded that personal protective measures were performed more frequently by those who had personal acquaintances with Lyme disease, those who believed the benefits of practicing the behavior outweighed the barriers, and those who believed Lyme disease was serious (Shadick et al. 1997).

Limitations

Limitations to the study occurred for dragging, human observations, and administering the surveys. Because I only sampled for ticks between late May to mid-August, I was unable to capture the peak activity of larvae and adult ticks. In doing so, I focused this study on nymphs; however, people can be exposed to low levels of adults and larvae throughout the summer months as well. Measuring tick density at a higher resolution would also provide more detailed information of tick abundance at a finer scale under 100 m. Additionally, only dragging methods were employed, and check distances were 20 m for all three species. I predominantly collected

H. longicornis, and there is currently no detailed information on the appropriate check distance for this species, so we do not know if 20 m check distances were the most effective method. CO_2 traps could also be deployed to increase *A. americanum* collections. Variability with the GPS tracking apps provided fluctuating levels of accuracy when tracking our dragging locations. This could have been further complicated by the heavy canopy and the difference in internal cell phone satellite readings. Finally, this study does not discuss the number of infected nymphs to estimate pathogen abundance in the tick population of *I. scapularis* and *A. americanum*.

In tracking the human usage of park spaces, I could not capture the exact location of park visitors unless I approached them to acquire a GPS coordinate (causing a disruption of unobstructed activity and invasion of privacy) or required that visitors wear sensors to map their movements. Thus, I could not distinguish if park visitors were coming into direct contact with ticks based on the GPS location of my drags given the degree of error associated with hand-drawn maps. Age ranges were estimated to the best of my ability and then grouped into four categories (child, teen, adult, and senior), eliminating the ability to see behavior at a finer age scale. Similarly, the number of park visitors is likely overestimated due to recording the same individuals returning to the parks multiple times across the summer, and it is not possible to know if individuals frequented multiple parks. In circumstances where the density of park visitors became too high in the sites, it became impossible to track the exact movement of all visitors and acquire complete demographic information. Similarly, when individuals crossed multiple habitats in one movement without pausing, I could not document the amount of time spent in each of those habitats given the quickness and frequency of many visitors crossing multiple habitats. The goal was to estimate tick exposure risk based on visitor behavior; however, other unmeasured factors may influence exposure risk, such as personal prevention measures used by the individuals entering the habitats. Importantly, it is not advised to extrapolate habitat use in these three parks to other parks because there are changes across facility availability, level of safety, and habitat maintenance that may drive individuals to use habitats differently in other parks.

When administering the KAP surveys, I could not interview individuals who did not speak English, and I could only interview people who were not actively engaged in an activity. Children and teens went into hazardous locations in the parks; however, I could not interview visitors under 18 years of age. I could not verify that individuals were interpreting the questions in the same way, which would make the questionnaire and responses stronger. I also could not interview park visitors that I mapped during the observational component since it would disrupt the visitors' natural behavior.

Recommendations

I found that tick density across parks was not homogenous and exposure was uneven based on the underlying heterogeneity in tick densities and visitation variation. In addition, checking for ticks was influenced by the known number of tick prevention methods, the perceived likelihood of tick encounter, and the knowledge of tick habitats. My results can contribute to refining public education on tick prevention methods and can be used to customize risk messaging by specific parks. Specifically, parks should be advised to post signs informing visitors of the presence of ticks in each park, highlighting the local species, to increase perceptions of susceptibility. This should be paired with safety information on the tick prevention methods available and reminders for adults to periodically check themselves, their children, and their pets for ticks during and after their park visit. Overall, visitors should be encouraged to engage in outdoor activities for the wellness benefits that green spaces provide while remaining proactive in preventing tick exposure.

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Appendices

Appendix 1. Knowledge Attitudes and Practices Survey.

KAP Goals: To survey individuals who go to parks on Staten Island, NY and test for association between knowledge and practices in regard to ticks and tick prevention. Information collected can be used for public health intervention strategies.

Statement

Hello, my name is Erin, and I am a graduate student at Cornell University, studying insects. I am doing research and asking park visitors about their opinion of the pros and cons of being outdoors in parks. We are trying to understand what drives people to and from parks involving ticks. Could I please ask you some questions?

It will take approximately 10-minutes, and it is completely voluntary, so you are welcome to stop the survey at any time. I will be writing down your answers, and it will remain confidential. Do you have any questions that I can answer? (Provide Contact Information)

- ☐ Do you agree to participate in this research? (Y/N)
- ☐ Over 18

****If 18 years or under, we will not continue with survey***

Pre-Sampling

1. Day of Week
   a. Weekday
   b. Weekend
2. Sampling Location
   a. Conference House
   b. Willowbrook
   c. Clove Lakes

3. Date____

4. Time____
5. Participant ID_____________________________________

Questionnaire (Answers will not be read aloud unless otherwise denoted)

First, we would like to know how far you are travelling to come to this park:

1. Are you a Staten Island resident? Yes / No (Circle)

If No, what city or borough do you live in?

If yes, what street intersection do you live the closest to?
Street 1: ____
Street 2: ____

2. On a 10-point scale, how would you rate your happiness right now? (With 1 being Not At All Happy and 10 being Extremely Happy)

   Answer:

3. How often do you come here or use this space in general?
   - ☐ 1 = several times a year
   - ☐ 2 = once a month
   - ☐ 3 = once a week
   - ☐ 4 = almost every day
   - ☐ First Time

4. What activities to you often do in the parks?
   - ☐ Dog walk
   - ☐ Sleeping
   - ☐ Walk/Run
   - ☐ Read
   - ☐ Picnic
   - ☐ Sports
   - ☐ Others____________________

5. On a 5-point scale, how much do you agree with the following statement: Being in [name of space] makes me feel happy.
   With 1 being strongly disagree, 2 being disagree, 3 being neither agree nor disagree, 4 being agree and 5 being strongly agree.__________________________

   ____

Now I will ask you some questions related to ticks:

6. Have you ever seen a tick? (Y/N)

7. Have you ever found a tick on you/ a member of your household? (Y/N)

8. Have you ever found a tick on your pet? (Y/N)

9. Which of these ticks have you seen?
   - ☐ 1
   - ☐ 2
   - ☐ 3

- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ None
- ☐ I don't know

10. Do you know which one transmits Lyme disease?
    - ☐ 1
    - ☐ 2
    - ☐ 3
    - ☐ 4
    - ☐ 5
    - ☐ 6
    - ☐ 7
    - ☐ 8
    - ☐ None
    - ☐ I don't know

11. Where do you think people are being exposed to ticks here on Staten Island?
    - ☐ Parks/ Natural areas
    - ☐ Their own yard
    - ☐ Someone else's yard
    - ☐ Woods
    - ☐ Grassy areas
    - ☐ Trails
    - ☐ Other: ____________________________

      ____

12. Have you ever avoided or stopped doing any activities because of the fear of tick exposure?

    If so, what?____

13. How serious a problem are tick-transmitted diseases on Staten Island on a scale of 1 to 5 with 1 being not at all serious and 5 being extremely serious, in relation to other health concerns you might have (read the options)
    - ☐ 5- extremely serious
    - ☐ 4- very serious
    - ☐ 3- somewhat serious
    - ☐ 2- Slightly serious
    - ☐ 1- Not at all serious
    - ☐ Not sure

14. How many people do you -including yourself- who has had Lyme disease?
- ☐ None
- ☐ Do they live on Staten Island?
  - Person 1 (Y/N)
  - Person 2 (Y/N)
  - Person 3 (Y/N)
- ☐ Are they a member of your household?
  - Person 1 (Y/N)
  - Person 2 (Y/N)
  - Person 3 (Y/N)

15. On a scale of 1-5, where 5 is very likely, how likely is it that you would encounter a tick on yourself or a member of your household this summer? (**Read options)**
    - ☐ 5- very likely (over 80% chance)
    - ☐ 4- Somewhat likely (between 51-80%)
    - ☐ 3- Equally likely/unlikely (50/50%)
    - ☐ 2-Somewhat unlikely (between 10-49% chance)
    - ☐ 1- Very unlikely (less than 10% chance)
    - ☐ Not sure

16. Can you tell me how ticks get infected with the Lyme bacteria?
    - ☐ Don't know
    - ☐ They all have it
    - ☐ By feeding on mice/ other small mammals
    - ☐ By feeding on deer
    - ☐ By feeding on an infected person
    - ☐ Other______________________
      ____

17. What tick prevention methods have you heard of?
    - ☐ Repellent
    - ☐ Wearing light colored clothing
    - ☐ Avoiding tick habitats
    - ☐ Wearing long sleeves
    - ☐ Tucking pants in socks
    - ☐ Bathing after outdoor activities
    - ☐ Vaccination
    - ☐ Other____
      ____
    - ☐ None
    - ☐ Not sure

18. How do ***you*** protect yourself from tick bites?
    - ☐ Check for ticks after being outdoors
    - ☐ Repellent

- ☐ Wearing light colored clothing
- ☐ Avoiding tick habitats
- ☐ Wearing long sleeves
- ☐ Tucking pants in socks
- ☐ Bathing after outdoor activities
- ☐ Vaccination
- ☐ None
- ☐ Not sure
- ☐ Other____

19. What would you do if you found a tick on yourself or a member of your household (as soon as you found one and after had found one)?
    - ☐ Remove it

    If so, how:
    ____
    - ☐ Apply Vaseline
    - ☐ Check for rash then see a doctor
    - ☐ Send the tick for testing
    - ☐ See a doctor/vet right away?
    - ☐ Report it on the tick app
    - ☐ Nothing
    - ☐ Don't know
    - ☐ Other____ ____________

20. How often do you check for ticks after being outdoors? (read answers)
    - ☐ Never
    - ☐ Some of the time
    - ☐ Every time outdoors

21. What would you say are the main reasons for skipping tick checks after being outdoors?
    - ☐ Forget
    - ☐ Don't have time
    - ☐ Laziness (don't want to)
    - ☐ Seasonal importance
    - ☐ Type of activity
    - ☐ It's not important
    - ☐ Not in an area with ticks
    - ☐ I don't know how they look like/what to look for
    - ☐ Other____ _____

22. How often do you use tick/insect repellent?
    - ☐ Never (1)

- ☐ Some of the time (2)
- ☐ Every time outdoors (3)
- ☐ If so, what kind ____

23. What are your concerns, if any, about using repellent?
    - ☐ Costs too much
    - ☐ Not worried about ticks/mosquitoes
    - ☐ Concerned about health/safety
    - ☐ Don't like smell or feel
    - ☐ Doesn't work
    - ☐ Don't think I need it
    - ☐ I don't have any concerns
    - ☐ Other____

24. What is your main source of information about tick-borne diseases?
    - ☐ School
    - ☐ Friend
    - ☐ Family
    - ☐ Vet
    - ☐ TV/radio
    - ☐ Internet
    - ☐ Other____

25. What do you think can be done on Staten Island to reduce the cases of Lyme disease (Don't read. Mark all mentioned)
    - ☐ Kill deer
    - ☐ Sterilize deer
    - ☐ Spray pesticides in natural area/parks
    - ☐ Spray pesticides in people's yards
    - ☐ Kill mice
    - ☐ Kill ticks on mice/deer
    - ☐ Nothing
    - ☐ Education
    - ☐ Monitoring
    - ☐ It's a personal matter (use of personal protective measures)
    - ☐ Other____

26. What is currently being done to control deer?
    - ☐ Reduce deer
    - ☐ Kill deer

- ☐ Sterilize deer/birth control
- ☐ Nothing
- ☐ I don't know
- ☐ other

27. What do you think about sterilizing deer to control the tick population?
    - ☐ It works/ will work
    - ☐ Costs too much
    - ☐ Not effective to reduce tick population
    - ☐ Other____
    - ☐ I don't know
28. Do you or a contractor apply pesticides targeting ticks, mosquitoes or other insects on your property? (Y/N)
    a. What pesticides/insecticide?
       Name____
    b. Organic (Y/N) or I don't know (Circle)
    c. During spring and summer, how often did you or a contractor apply pesticides on your property?
       i. About once a season (3)
       ii. About once a month (2)
       iii. About once a week (1)
29. What are your concerns, if any, about spraying with synthetic pesticides?
    - ☐ Costs too much
    - ☐ Not worried about ticks
    - ☐ Concerned about environmental issues
    - ☐ Concerned about health/safety
    - ☐ Doesn't work
    - ☐ Don't think I need it
    - ☐ I don't have any
    - ☐ Other
    - ☐ I don't know
30. What are your concerns, if any, about spraying with organic pesticides?
    - ☐ Costs too much
    - ☐ Not worried about ticks
    - ☐ Concerned about environmental issues
    - ☐ Concerned about health/safety
    - ☐ Doesn't work
    - ☐ Don't think I need it
    - ☐ I don't have any concerns
    - ☐ Other
    - ☐ I don't know

Demographics

31. Age_____________________________

32. Gender (don't ask)
    a. Male
    b. Female

33. How would you classify yourself in regards to race?
    ____

34. Do you consider yourself Hispanic or Latino? (Y/N)

35. What is the highest level of education you have completed?
    ____

Observational

36. Is participant in: Sun or Shade
    a. Sun
    b. shade
37. Respondent Activity:
    a. Socializing
    b. Eating
    c. Reading print material
    d. Using phone
    e. Reading
    f. Sitting on bench
    g. Walking
    h. With dog
    i. With children
    j. Listening to music
    k. Drinking coffee
    l. Other:

38. Current Weather
    a. Sunny
    b. Overcast
    c. Other____
39. Respondent location within the park
    a. Playground
    b. Walking on path
    c. Sitting along path

Appendix 2. Model selection for each nymph species. Included in the model are drag habitat, park, site type, and dragging distance offset in meters. Variables designated with "+" are included, and the model with the lowest AIC value was selected. Model 2 for *A. americanum* was chosen since it was the full model and was within two AIC values from Model 1.

Model	Drag Habitat	Park	Site Type	Offset (m)	DF	AIC
H. longicornis						
1	+	NA	+	+	5	917.3
2	+	NA		+	3	920.3
3		NA	+	+	4	929.2
4	+	NA	+		5	934.2
5	+	NA			3	936.0
6		NA	+		4	944.1
7		NA		+	2	981.2
8		NA			2	990.5
A. americanum						
1		+	+	+	6	426.9
2	+	+	+	+	8	427.3
3	+	+		+	6	428.8
4		+	+		6	438.9
5	+	+	+		8	439.3
6	+	+			6	439.5
7		+		+	4	445.0
8		+			4	454.9
9	+		+	+	6	482.6
10	+		+		6	497.5
I. scapularis						
1	+	+		+	6	331.6
2	+	+	+	+	8	335.2
3	+	+			6	337.9
4	+		+	+	6	339.4
5	+			+	4	340.8
6	+	+	+		8	341.5
7		+	+	+	6	443.3
8	+		+		6	346.5
9	+				4	347.6
10		+		+	4	347.7
11			+	+	4	347.8
12		+	+		6	350.7
13		+			4	354.4
14			+		4	355.9
15				+	2	359.3
16					2	366.3

Appendix 3. Life stage densities for each species in every park and site. The number of ticks per 100 m^2 is shown for *I. scapularis (I.s), A. americanum (A.a)* and *H. longicornis (H.l)*.

Park	Site	Total Drags	Total Distance (m^2)	*I.s* larvae	*I.s* nymph	*I.s* adult	*A.a* larvae	*A.a* nymph	*A.a* adult	*H.l* larvae	*H.l* nymph	*H.l* adult
Clove Lakes	Open Space 1	40	4063	0	0	0	0	0	0	0	0	0
	Open Space 2	34	2955	0	0	0	0	0	0	0	0	0
	Open Space 3	34	3249	0	0	0	0	0	0	0	0	0
	Trail 1	13	1774	0	0	0	0	0	0	0	0	0
	Trail 2	12	1349	0	0	0	0	0	0	0	0	0
	Trail 3	18	2035	0	0	0	0	0	0	0	0	0
	Trail 3 ext	4	411	0	0	0	0	0	0	0	0	0
	Trail 6	11	629	0	0	0	0	0	0	0	0	0
Conference House	Open Space 1	49	5411	0	0	0	5	1	0	25	15	3
	Open Space 2	24	2762	0	0	0	1	0	0	2	4	1
	Trail 1	29	3398	1	1	0	25	2	0	73	25	8
	Trail 2	32	3238	0	0	0	15	2	0	5	26	1
Willowbrook	Open Space 1	38	3100	0	0	0	2	0	0	0	0	0
	Open Space 2	36	3687	21	0	0	4	0	0	0	0	0
	Trail 1	25	238	0	1	0	0	0	0	0	0	0
	Trail 2	31	3316	0	0	0	0	0	0	0	0	0

Appendix 4. Nymph counts (n) and density per 100 m^2 (d) by drag habitat and park.

Park	Drag Habitat	Total Distance (m^2)	*A. americanum* n (d)	*I. scapularis* n (d)	*H. longicornis* n (d)
Clove Lakes	Leaf Litter	5873	1 (0.02)	10 (0.17)	0
	Maintained Grass	3218	0	0	0
	Unmaintained Herbaceous	7075	2 (0.03)	7 (0.10)	0
Conference House	Leaf Litter	NA	NA	NA	NA
	Maintained Grass	3914	7 (0.18)	0	43 (1.10)
	Unmaintained Herbaceous	10895	143 (1.31)	59 (0.54)	2556 (23.46)
Willowbrook	Leaf Litter	4715	2 (0.04)	6 (0.13)	0
	Maintained Grass	3346	1 (0.03)	1 (0.03)	0
	Unmaintained Herbaceous	4424	1 (0.02)	2 (0.05)	0

Appendix 5. Nymph counts (n) and density per 100 m^2 (d) by site type and park. Open spaces had either an edge (E) or no edge (NE).

Park	Site Type	Total Distance (m^2)	*A. americanum* n (d)	*I. scapularis* n (d)	*H. longicornis* n (d)
Clove Lakes	Open Space NE	5385	1 (0.02)	7 (0.13)	0
	Open Space E	4741	2 (0.04)	5 (0.11)	0
	Trail	6040	0	5 (0.08)	0
Conference House	Open Space NE	4248	8 (0.19)	0	79 (1.86)
	Open Space E	1043	0	1 (0.10)	70 (6.71)
	Trail	9518	142 (1.49)	58 (0.61)	2450 (25.74)
Willowbrook	Open Space NE	3777	2 (0.05)	1 (0.03)	0
	Open Space E	3010	1 (0.03)	1 (0.03)	0
	Trail	5698	1 (0.02)	7 (0.12)	0

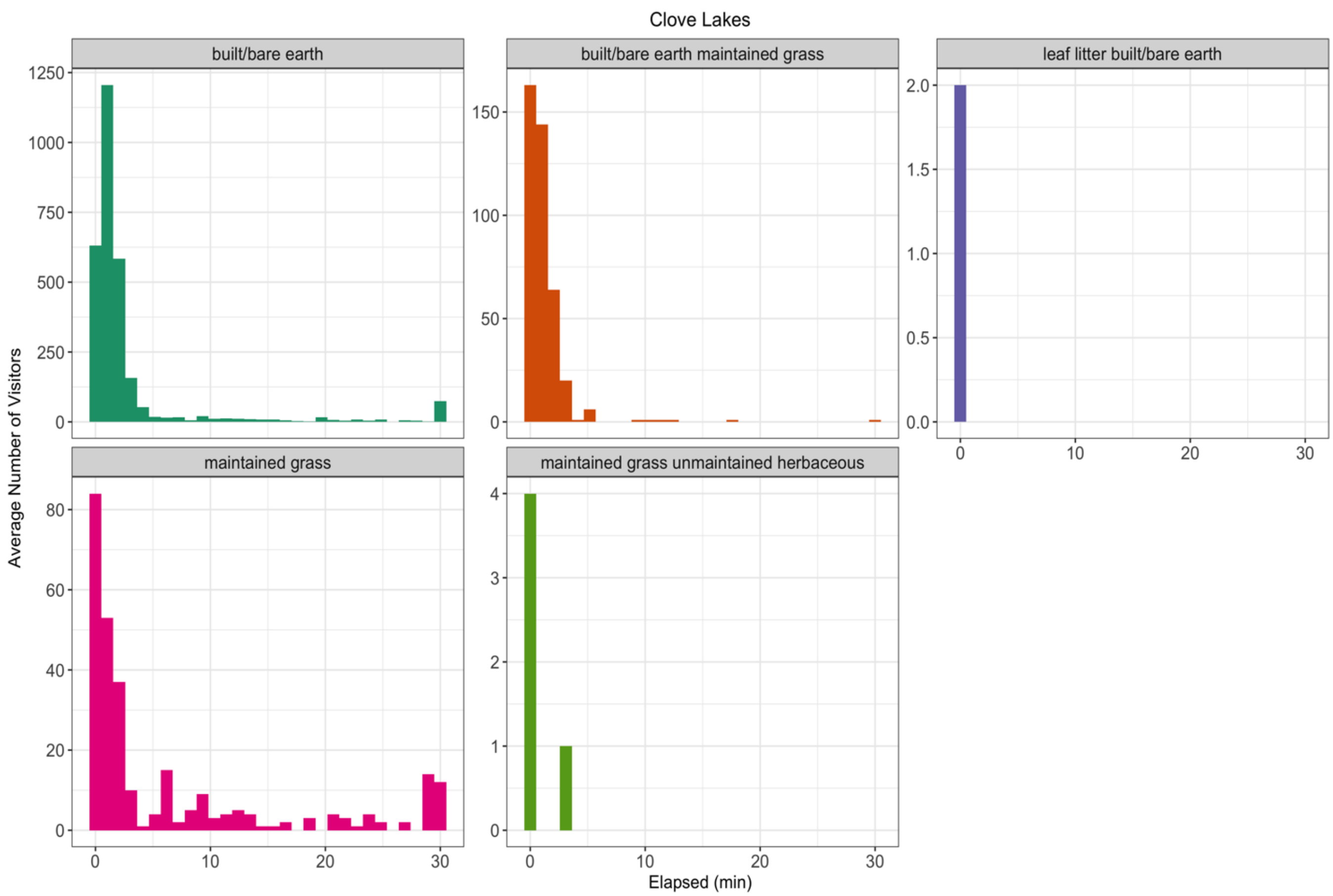
Appendix 6. Visitation by gender in each park, site type, and habitat. Counts (n) and within-gender proportions (%) are represented. Habitats include built/ bare earth (BBE), maintained grass (MG), leaf litter (LL), and unmaintained herbaceous (UH).

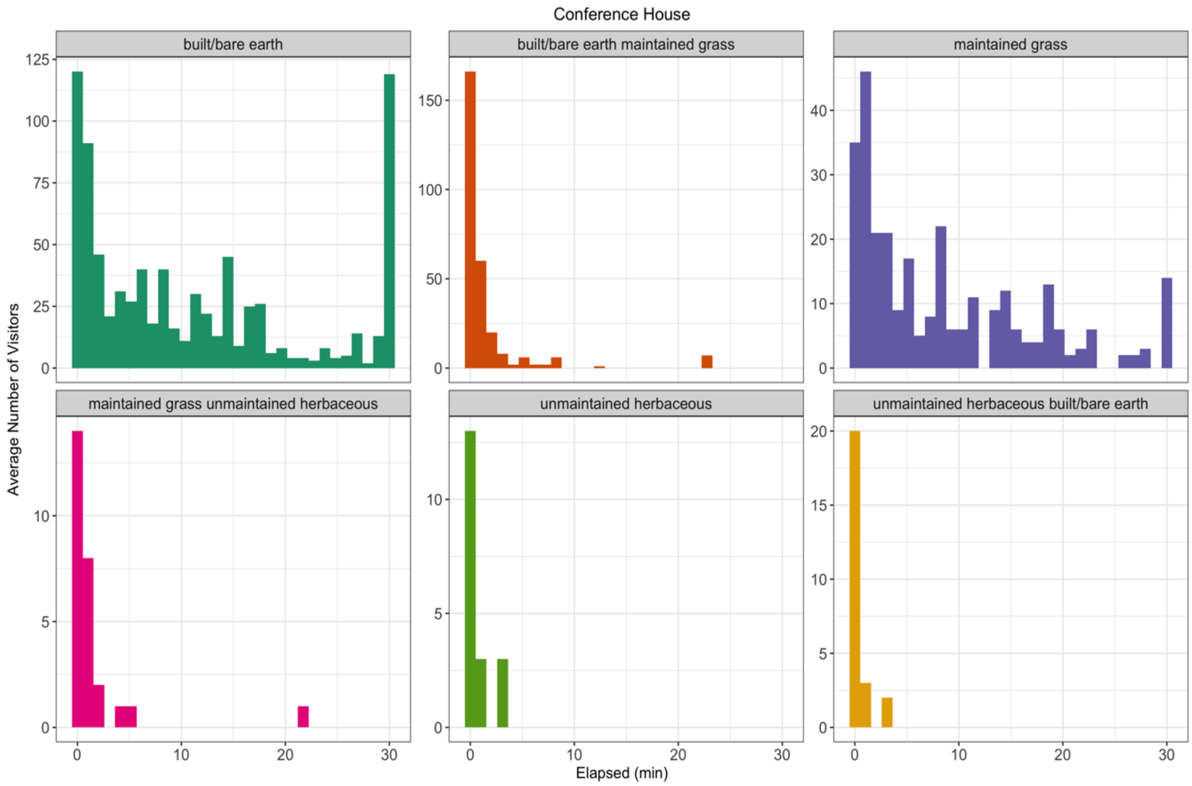
Park	Gender	Site Type n (%)		Habitat n (%)								
		Open Space	Trail	BBE	BBE-MG	MG	MG-UH	UH	BBE-UH	LL	BBE-LL	MG-LL
Clove Lakes	Female	1145 (96)	46 (3.9)	1048 (88)	110 (9.2)	73 (6.1)	1 (<1)	28 (2.3)	0	18 (1.5)	0	0
	Male	1481 (94.8)	82 (5.2)	1350 (86.4)	203 (13)	99 (6.3)	2 (<1)	46 (2.9)	0	36 (2.3)	2 (<1)	0
Conference House	Female	451 (85.3)	78 (14.7)	339 (64)	108 (20.4)	83 (15.7)	9 (1.7)	83 (15.7)	7 (1.3)	0	0	0
	Male	474 (73.1)	174 (26.9)	302 (46.6)	142 (21.9)	105 (16.2)	14) (2.1)	188 (29)	14 (2.2)	0	0	0
Willow-brook	Female	670 (73.4)	242 26.5)	411 (45)	66 (7.2)	330 (36.2)	0	221 (24.2)	0	23 (2.5)	0	11 (1.2)
	Male	732 (73)	271 (27)	474 (47.3)	48 (4.7)	311 (31)	0	239 (23.8)	0	39 (3.9)	0	35 (3.5)

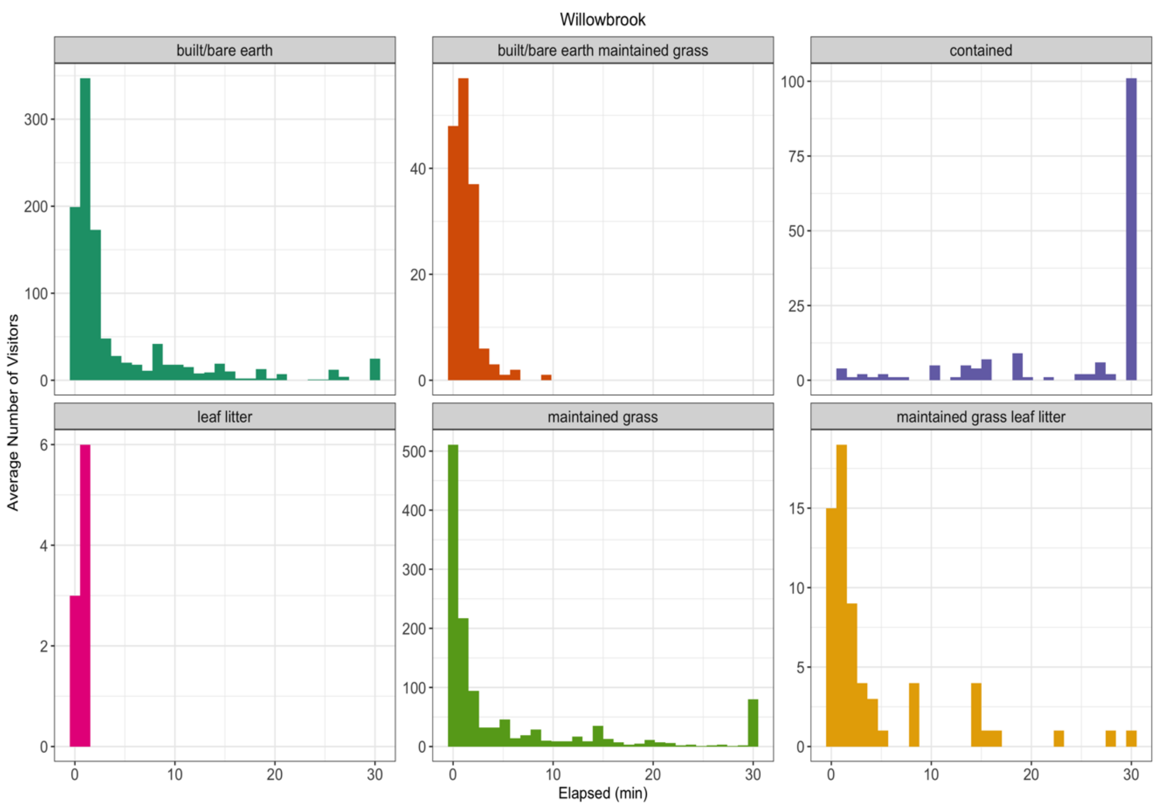
Appendix 7. Counts (n) and within-group proportion (%) of visitors by age group in each park, site type, and habitat. Habitats include built/ bare earth (BBE), maintained grass (MG), leaf litter (LL), and unmaintained herbaceous (UH).

Park	Age	Site Type n (%)		Habitat n (%)								
		Open Space	Trail	BBE	BBE-MG	MG	MG-UH	UH	BBE-UH	LL	BBE-LL	MG-LL
Clove Lakes	Child	194 (97)	6 (3)	160 (80)	33 (16.5)	31 (15.5)	1 (0.5)	6 (3)	0	1 (0.5)	0	0
	Teen	196 (94.7)	11 (5.3)	170 (82.1)	39 (18.8)	11 (5.3)	0	10 (4.8)	0	1 (0.5)	0	0
	Adult	1791 (95.4)	86 (4.5)	1656 (88.2)	198 (10.5)	112 (6.5)	1 (0.05)	44 (2.3)	0	42 (2.2)	2 (0.1)	0
	Senior	468 (95.5)	22 (4.5)	432 (88.2)	47 (9.6)	20 (4.1)	1 (0.2)	13 (2.7)	0	9 (1.8)	1 (0.2)	0
Conference House	Child	268 (93.1)	20 (6.9)	233 (80.9)	46 (16)	28 (9.7)	0	22 (7.6)	1 (<1)	0	0	0
	Teen	121 (80.1)	30 (19.9)	85 (56.3)	35 (23.2)	34 (22.5)	2 (1.3)	34 (22.5)	0	0	0	0
	Adult	438 (75.3)	144 (24.7)	271 (46.6)	132 (22.7)	102 (17.5)	18 (3.1)	149 (25.6)	13 (2.2)	0	0	0
	Senior	108 (65)	58 (34.9)	56 (33.7)	36 (21.7)	24 (14.5)	3 (1.8)	66 (39.8)	8 (4.8)	0	0	0
Willow-brook	Child	347 (86.3)	55 (13.7)	241 (60)	33 (8.2)	202 (50.2)	0	50 (12.4)	0	4 (0.01)	0	19 (4.7)
	Teen	105 (60.3)	69 (39.7)	65 (37.4)	3 (1.7)	44 (25.3)	0	69 (39.7)	0	2 (1.1)	0	2 (1.1)
	Adult	859 (72.4)	328 (27.6)	474 (39.9)	66 (5.6)	363 (30.6	0	284 (23.9)	0	50 (42.1)	0	22 (1.9)
	Senior	152 (71)	62 (29)	107 (0.5)	12 (5.6)	35 (16.4)	0	57 (26.6)	0	6 (2.8)	0	4 (1.9)

Appendix 8. Duration of time spent in each habitat per park. In areas where two habitats are listed, visitors crossed multiple habitats. Visitors are recorded multiple times if they encountered multiple habitats.




Conference House
built/bare earth
built/bare earth maintained grass
maintained grass
maintained grass unmaintained herbaceous
unmaintained herbaceous
unmaintained herbaceous built/bare earth
Average Number of Visitors
Elapsed (min)


Willowbrook
built/bare earth
built/bare earth maintained grass
contained
leaf litter
maintained grass
maintained grass leaf litter
Average Number of Visitors
Elapsed (min)

Appendix 9. The number of visitors (n) that engaged in each activity in each habitat for a duration of time (min). Information includes both trail and open space site types. Time spent cannot be captured for individuals in trails. Individuals may be recorded multiple times if their activities changed during the time spent in a specific habitat.

Park	Habitat Type	Activity	Time (min)	n
Open Space				
Clove Lakes	built/bare earth	walking	NA	1703
		jogging/running	0.6	396
		biking	0.4	117
		exercising	6.8	84
		sitting	NA	84
		standing	NA	84
		picnicking	19.9	72
		fishing	22.4	53
		walking	1.2	9
		driving	3.0	6
		scooter	1.6	5
		playing	2.4	4
		socializing	18.5	4
		working	6.3	4
		motorized chair	0.7	3
		feeding geese	3.0	3
		horseback riding	1.0	2
		reading	20.0	2
		photography	3.0	2
		wheelchair	2.0	2
		sports	30.0	1
		exercising	2.0	1
		skateboarding	0.0	1
		skating	0.0	1
	built/bare earth-maintained grass	walking	1.0	287
		jogging/running	0.8	11
		driving	0.4	8
		exercising	10.3	6
		biking	0.7	2
		picnicking	0.0	2

		standing	0.5	2
		walking	5.0	2
		birding	11.0	1
		working	9.0	1
	leaf litter built/bare earth	walking	0.0	2
	maintained grass	walking	0.7	54
		standing	1.7	50
		picnicking	17.9	49
		sitting	12.7	40
		driving	0.8	6
		exercising	10.3	3
		sports	11.3	3
		tanning	10.5	2
		working	4.0	2
		yoga	27.0	2
		birding	4.0	1
	maintained grass unmaintained herbaceous	jogging/running	0.0	2
		walking	3.0	1
Conference House	built/bare earth	playground	NA	438
		walking	NA	102
		touring	4.8	35
		biking	NA	30
		sitting	11.0	29
		standing	7.3	25
		photoshoot	24.9	14
		gardening	22.1	13
		socializing	13.5	6
		exercising	10.7	3
		photography	3.5	3
		driving	2.5	2
		playing	7.0	2
		working	6.0	1
	built/bare earth-maintained grass	walking	0.7	167
		touring	0.0	37
		photography	14.0	14
		biking	0.3	9
		walking	3.3	8
		sitting	5.0	4

		sports	0.0	2
		working	0.2	2
		photoshoot	1.0	2
		playground	0.0	2
		jogging/running	0.0	1
		tanning	0.0	1
	maintained grass	sitting	14.1	56
		walking	1.8	53
		picnicking	16.4	34
		touring	7.6	21
		standing	6.3	20
		sports	7.6	13
		playground	NA	8
		working	3.2	6
		tanning	20.0	5
		photoshoot	5.8	5
		biking	1.8	4
		playing	10.0	2
		painting	30.0	2
		stretching	2.0	1
		violin	15.0	1
	maintained grass unmaintained herbaceous	walking	1.7	20
		biking	0.0	1
		driving	1.0	1
		working	3.0	1
	unmaintained herbaceous	walking	0.7	16
		playground	0.5	2
		touring	0.0	1
	unmaintained herbaceous built/bare earth	walking	0.6	15
		biking	0.0	3
		walking	0.0	3
		jogging/running	0.0	1
Willowbrook	built/bare earth	walking	NA	530
		playground	NA	262
		biking	NA	45
		sitting	12.7	31
		jogging/running	0.3	25
		scooter	0.4	9
		standing	4.1	8

		driving	1.7	3
		playing	2.0	3
		picnicking	1.0	1
		reading	30.0	1
	built/bare earth maintained grass	walking	1.2	109
		standing	1.0	4
		playground	1.0	3
		biking	1.0	1
		driving	1.0	1
	contained	contained	25.1	91
		picnicking	NA	47
		playground	12.8	3
		playing	10.0	2
		sitting	30.0	2
		walking	12.5	1
	leaf litter	walking	0.6	8
		biking	1.0	1
	maintained grass	walking	0.6	505
		sitting	12.7	150
		picnicking	17.5	120
		standing	5.0	106
		sports	12.3	9
		jogging/running	0.3	8
		playing	13.5	8
		playground	0.4	6
		working	2.8	5
		driving	6.3	4
		socializing	8.0	2
		yoga	29.0	2
		tanning	8.0	1
		photography	4.3	1
		metal detector	5.0	1
		contained	13.0	1
	maintained grass leaf litter	walking	2.8	32
		playing	13.6	8
		jogging/running	0.5	4
		standing	1.5	4
		sitting	2.5	2
		picnicking	30.0	1

Trail				
Clove Lakes	leaf litter	walking	NA	44
		jogging/running	NA	5
		biking	NA	3
	unmaintained herbaceous	walking	NA	40
		jogging/running	NA	27
		biking	NA	5
		stretching	NA	1
Conference House	unmaintained herbaceous	walking	NA	165
		biking	NA	59
		jogging/running	NA	24
		sitting	NA	2
		birding	NA	1
		standing	NA	1
Willowbrook	leaf litter	walking	NA	49
		standing	NA	2
		biking	NA	1
	unmaintained herbaceous	walking	NA	423
		jogging/running	NA	17
		fishing	NA	10
		sitting	NA	5
		biking	NA	4
		working	NA	4
		driving	NA	1
		playing	NA	1
		standing	NA	1

Appendix 10. KAP survey responses.

General Information and Demographics		
Age	18-28	27 (14.2)
	29-39	29 (15.3)
	40-50	34 (17.9)
	51-61	32 (16.8)
	62-72	39 (20.5)
	73-83	17 (8.9)
	NA	12 (6.3)
Gender	Male	109 (57.4)
Race	American Indian/Alaskan Native	1 (0.5)
	Black/African American	13 (6.8)
	Multi-racial	7 (3.7)
	Asian/ Pacific Islander	10 (5.3)
	White/Caucasian	112 (58.9)
	Other	32 (16.8)
	NA	15 (7.9)
Hispanic or Latino	No	153 (80.5)
	Yes	28 (14.7)
	NA	9 (4.7)
Education level	High school or less	41 (21.6)
	Some College/Associates	71 (37.4)
	Bachelor's degree	27 (14.2)
	Graduate or professional degree	24 (12.6)
	NA	27 (14.2)
Staten Island resident	Yes	176 (92.6)
General happiness on a 1-10 scale	1	2 (1.1)
	2	2 (1.1)
	4	5 (2.6)
	5	7 (3.7)
	6	6 (3.2)
	7	21 (11.1)
	7.5	5 (2.6)
	8	48 (25.4)
	8.5	3 (1.6)
	9	33 (17.5)
	9.5	2 (1.1)
	10	55 (29.1)
Happiness level in the park (1-5 scale)	2	1 (0.5)
	3	18 (9.6)
	4	46 (24.5)

	4.5	3 (1.6)
	5	120 (63.8)
Source of information about ticks and tick-borne diseases	Schooling	4 (2.2)
	Friend	5 (2.7)
	Family	3 (1.6)
	Vet	3 (1.6)
	TV/Radio	37 (20)
	Internet	77 (41.6)
	Social	6 (3.2)
	Word of mouth	10 (5.4)
	News	10 (5.4)
	None	15 (8.1)
	Personal experience	19 (10.2)
	Park	9 (4.8)
	Outreach	6 (3.2)
	Book	8 (4.3)
	Other	20 (10.8)
Tick Exposure		
Have you seen a tick?	Yes	114 (60)
Have you found a tick on you or household member?	Yes	61 (53.5)
Have you found a tick on your pet?	Yes	62 (54.4)
Do you know anyone with Lyme?	Yes	84 (44.2)
	One person	58 (30.9)
	Two people	23 (12.4)
	Three people	12 (6.5)
	More than three	13 (7)
Does the person with Lyme disease live on Staten Island?	Person 1	77 (73.3)
	Person 2	30 (63.8)
	Person 3	12 (50)
Is the person with Lyme disease a member of your house?	Person 1	19 (18.3)
	Person 2	2 (4.2)
	Person 3	0 (0)
Knowledge		
Tick identification: Which of these are ticks?	Eastern ash bark beetle	11 (9.7)
	American dog tick	72 (63.7)
	Swallow bug	8 (7.1)
	Drugstore bug	3 (2.7)

	Lone star tick	43 (38.1)
	Deer tick adult	30 (26.5)
	Flea	5 (4.4)
	Deer tick nymph	4 (3.5)
	None	3 (2.7)
	I don't know	16 (14.2)
Which tick transmits Lyme disease?	Eastern ash bark beetle	8 (7.1)
	American dog tick	18 (15.9)
	Swallow bug	9 (8)
	Drugstore bug	9 (8)
	Lone star tick	13 (11.5)
	Deer tick adult	19 (16.8)
	Flea	19 (16.8)
	Deer tick nymph	9 (8)
	None	2 (1.8)
	I don't know	78 (69)
Where are people getting exposed to ticks?	Parks	82 (43.2)
	Yards	12 (6.3)
	Woods	52 (27.4)
	Grass	32 (16.8)
	Trails	7 (3.7)
	Deer Areas	24 (12.6)
	Everywhere	10 (5.3)
	Water	6 (3.2)
	Other	14 (7.4)
	I don't know	22 (11.6)
How do ticks get infected with Lyme disease?	All are infected	3 (1.6)
	Mice	16 (8.4)
	Deer	43 (22.6)
	Infected animals	17 (8.9)
	Other	6 (3.2)
	I don't know	121 (63.7)
Knowledge prevention methods	Repellent	117 (61.6)
	Light colored clothing	15 (7.9)
	Avoid tick habitat	68 (35.8)
	Long sleeves	76 (40)
	Pants into socks	44 (23.2)
	Shower	10 (5.3)
	Vaccine	4 (2.1)

	Tick check	47 (24.7)
	Pet repellent	7 (3.7)
	Other	34 (17.9)
	None	33 (17.4)
What would you do if you found a tick?	Remove	136 (72)
	Remove: Tweezers	70 (51.5)
	Remove: Fingers	20 (14.7)
	Remove: Burn	16 (11.8)
	Remove: Kill	8 (5.9)
	Remove: Vaseline	9 (6.6)
	Send it for testing	8 (4.2)
	Go to doctor	52 (27.5)
	Other	16 (8.5)
	I don't know	4 (2.1)
How to reduce Lyme disease on Staten Island?	Spraying	65 (34.9)
	Education	55 (29.6)
	Deer control/reduction	33 (17.7)
	Other	20 (10.8)
	I don't know	19(10.2)
	Personal protection measures	15 (8.1)
	Vegetation management	12 (6.5)
	Nothing can be done	8 (4.3)
	Mice control	6 (3.2)
	Tick reduction	6 (3.2)
	Increase predators of ticks (e.g. opossums)	4 (2.2)
	Monitor/surveillance	2 (1.1)
Attitudes		
How serious are tick-transmitted diseases on Staten Island?	Not at all serious	14 (7.4)
	Slightly serious	16 (8.4)
	Somewhat serious	42 (22.1)
	Very serious	33 (17.4)
	Extremely serious	47 (24.7)
	Not sure	38 (20)
Reasons for not using repellent?	Cost	0 (0)
	Worry	1 (0.5)
	Health	75 (40.1)
	Feel	12 (6.4)

	Ineffective	4 (2.1)
	Need	7 (3.7)
	None	90 (48.1)
	Other	6 (3.2)
Perceived probability of tick encounter	Very unlikely	82 (43.4)
	Somewhat unlikely	16 (8.5)
	Equally likely/unlikely	30 (15.9)
	Somewhat likely	13 (6.9)
	Very likely	33 (17.5)
	Not sure	15 (7.9)
Reasons for not checking for ticks	Forget	22 (11.7)
	No time	15 (8)
	Laziness	23 (12.2)
	Seasonality importance	2 (1.1)
	Activity dependent	5 (2.7)
	Not important	18 (9.6)
	Area dependent	46 (24.5)
	No previous experience with ticks	19 (10.1)
	Don't think to do it	19 (10.1)
	Negligence	7 (3.7)
	Ignorance	13 (6.9)
	I don't know	13 (6.9)
	Always checks	13 (6.9)
	Other	8 (4.3)
Practices		
Visitation frequency	Several times a year	31 (16.3)
	Once a month	20 (10.5)
	Once a week	19 (10)
	Several times a week	35 (18.4)
	Almost everyday	69 (36.3)
	First time	13 (6.8)
	Other	3 (1.6)
Park activities	Dog walk	39 (20.5)
	Walk/ run/ hike	102 (53.7)
	Read	6 (3.2)
	Picnic	8 (4.2)
	Sports	16 (8.4)
	Relax	28 (14.7)

	Play	15 (7.9)
	Fish	10 (5.3)
	Bike	12 (6.3)
	Work	14 (7.4)
	Park events	13 (6.8)
	Art	11 (5.8)
	Watch wildlife	13 (6.8)
	Other	20 (10.5)
Changed activities because of ticks?	Yes	48 (25.3)
What personal protection methods do you use?	Repellent	54 (28.6)
	Light colored clothing	7 (3.7)
	Avoid Habitat	58 (30.7)
	Long Sleeves	49 (25.9)
	Pants into socks or wearing long socks	26 (13.8)
	Shower	8 (4.2)
	Tick Check	34 (18)
	Other	13 (6.9)
	None or I don't know	62 (32.8)
Tick check frequency	Never	79 (42)
	Some of the time	28 (14.9)
	All of the time	71 (37.8)
Repellent use	Never	83 (44.6)
	Some of the time	57 (30.6)
	All of the time	46 (24.7)