OPPORTUNITIES AND BARRIERS IN THE CONTROL AND PREVENTION OF LYME DISEASE: IMPLICATIONS FOR PRACTICE

Philip W. Downs

A dissertation submitted to the faculty at the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctor of Public Health in the Department of Health Policy and Management in the Gillings School of Global Public Health.

Chapel Hill
2014

Approved by:

Suzanne Hobbs

Sandra Greene

Bryan Weiner

John E. Paul

Marcia Herman-Giddens

ABSTRACT

Philip W. Downs: OPPORTUNIITES AND BARRIERS IN THE CONTROL AND PREVENTION OF LYME DISEASE: IMPLICATIONS FOR PRACTICE
(Under the direction of Suzanne Hobbs)

Lyme disease is currently the most infectious disease in North America with 300,000 people estimated to be diagnosed with this tick-borne infection per year. While various tick control and Lyme disease prevention practices are documented in the literature review, and comprehensively reflected in an integrated pest management (IPM) strategy, translational studies suggest that very few practices are implemented on a routine basis to influence disease transmission. Public and private sector stakeholders are increasingly playing an important role in tick control and educating populations about personal protective measures.

To understand the influence of the public and private sector on the frequency and coverage of Lyme disease control and prevention practices in Maryland during 2009-2014, interviews were conducted with key informants from the federal, state, and non-profit sector. In addition, public and private sector stakeholders from counties with a high incidence of Lyme disease (greater than 50 cases per 100,000 during 2008-2012) participated in an online survey to describe their role in tick control and Lyme disease activities. Results of these interviews provided context to understanding current control and prevention efforts, including the role of the state and county in the implementation of IPM.

Results showed significant contributions by the public and private sector in supporting tick control and tick-borne disease prevention practices in Maryland. All major components of IPM were identified in at least one of the targeted counties. Control and prevention practices were not homogenous across counties, reflecting potential differences in stakeholder engagement. To navigate the uncertainty of control and prevention

strategies and to create a more comprehensive and inclusive structure for managing IPM, an adaptive resource management (ARM) strategy is recommended.

Four major recommendations are supported by study results, including: 1) formation of county level tick borne disease (TBD) committees as sponsors of IPM change initiatives, 2) facilitation of stakeholder engagement and communication plan workshops, 3) adoption of a behavior change communication (BCC) framework into personal protective measures for TBDs, and 4) development of a state organized IPM certification program for pest control operators and landscape companies.

To the communities fighting on the frontlines against tick-borne diseases.

ACKNOWLEDGEMENTS

This work would not have been possible without the encouragement and support of family, friends, colleagues, and classmates. Special gratitude goes to my wife Jillian and daughters Ava and Louise who were constant companions and supporters throughout this process. In experiencing Lyme disease myself, and watching several family members suffer as well, I am constantly reminded that more needs to be done to prevent this debilitating disease.

The guidance provided to me by my key informants was invaluable. Their personal contribution in the control and prevention of Lyme disease and dedication in serving the needs of communities remains an inspiration to me. I'm equally indebted to the various public and private stakeholders who participated in the study and offered their perspectives on tick control and Lyme disease prevention, even when they felt their organizations played a limited role.

I sincerely thank each of my committee members for their time and suggestions in formulating an approach to this study. I am especially honored to have Dr. Suzanne Hobbs as my dissertation committee chair; when my ideas were broadening in scope and becoming overwhelming, you always provided the needed prospective in how to break the problem down into manageable parts.

To cohort 7 – thank you for you humor, creativity, intellect, and friendship. The world needs leaders like you to manage the chaos and uncertainty that is inherent to our profession.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ARM	Adaptive Resource Management
CDC	Centers for Disease Control and Prevention
CSTE	Council of State and Territorial Epidemiologists
CZVD	Center for Zoonotic and Vector-borne Diseases
DHMH	Department of Health and Mental Hygiene
EM	Erythema migrans
IDEHA	Infectious Disease and Environmental Health Administration
IDSA	Infectious Disease Society of America
IPM	Integrated Pest Management
NEATCP	Northeast Area-wide Tick Control Project
NNDSS	National Notifiable Disease Surveillance System
OspA	Outer surface protein A
STARI	Southern Tick-Associated Rash Illness
TBD	Tick-borne disease
TBD-IPM-WG	Tick-borne disease integrated pest management workgroup
TBDDSS	Tick-borne disease decision support system
UMD	University of Maryland
URI	University of Rhode Island

USAPHC	Entomological Science Program at the US Army Public Health Command
USDA-ARS	United States Department of Agriculture- Agricultural Research Service

CHAPTER 1: INTRODUCTION

Statement of the Issue

The influence of the public and private sector on tick control and tick-borne disease (TBD) prevention practices is not well understood. Although an increasing number of evidence-based practices for the control and prevention of Lyme disease are publicly available, there is a paucity of information on the actual frequency and spatiotemporal coverage of interventions among endemic communities. Indeed, the lack of evidence from translational research suggests that very few TBD control and prevention practices are being successfully applied (R. J. Eisen, Piesman, Zielinski-Gutierrez, & Eisen, 2012; Piesman & Eisen, 2008). TBD and tick control, which are relatively new problems for federal and state governments, are typically framed as an individual problem instead of a community-wide issue. Consequently, in high risk, high prevalent areas for Lyme disease, a sudden or gradual decrease in cases, even after community-based control and prevention practices are implemented, is met with skepticism – uncertain of whether a reduction is related to changes in ecology, case reporting, surveillance practices, or the impact of control and prevention practices.

In North America, *Borrelia burgdorferi* is the causative agent for Lyme disease, or Lyme borreliosis; a gram negative, spirochetal bacteria spread through the bite of an infected black-legged tick (*Ixodes scapularis* and *Ixodes pacificus*) (Burgdorfer et al., 1982). Lyme disease first became a nationally reportable disease by the U.S. Centers for Disease Control and Prevention (CDC) in 1991. Over the last twenty-one years the number of reported Lyme disease cases according to surveillance criteria has increased by 175% from 9,908 confirmed cases in 1992 to 27,203 confirmed and 9,104 probable in 2013.After

analyzing medical claims over a 6 year period, CDC estimates that 300,000 people are diagnosed with Lyme disease each year (Kuehn, 2013). Lyme disease is now the most commonly reported vector-borne disease in North America, with 94% of all cases reporting from 12 States in 2011 including (from highest to lowest): Connecticut, Delaware, Maine, Maryland, Massachusetts, Minnesota, New Jersey, New Hampshire, New York, Pennsylvania, Virginia, and Wisconsin.

Lyme disease is a multisystem illness characterized by clinical presentations that most often involves the skin, joints, nervous system, and heart. Initial symptoms are frequently described as flu-like, including a general lack of energy, headache and stiff neck, fever and chills, muscle and joint pain, and swollen lymph nodes (Fell, 2000). Currently, no definitive diagnostic test is available for Lyme disease; therefore the absence or lack of laboratory confirmation should not exclude a suspected individual from treatment, although in some medical practices a lack of laboratory evidence excludes individuals from antibiotic treatment. If not detected and treated early enough, infection may further affect the skin, joints, nervous system, and heart within weeks to months after initial infection. Heart, nervous system, and joint symptoms may be the first signs of Lyme disease in people who do not develop minor cutaneous erythema migrans (EM), or other symptoms of early infection. As an outward sign of infection, EM is typically described as a central clearing lesion, or bulls-eye rash, but can present itself in many different forms including disseminated lesions, blue-red lesions, blistering lesions, and uniformly red lesions. Not all infected persons will present with EM, and presentation of the EM may go undetected by infected individuals.

More serious symptoms can present with late persistent infections including damage to the joints, nerves, and brain (Centers for Disease Control and Prevention. National Center for Emerging and Zoonotic Infectious Diseases (NCEZID) Division of Vector-Borne Diseases (DVBD), November 15, 2011). Correct diagnosis of Lyme disease remains a challenge for

many patients, who often endure an extended period of illness and multiple doctor visits before receiving appropriate treatment. A majority of Lyme disease patients have reported visiting an emergency room at least once as a result of Lyme disease (L. Johnson, Aylward, & Stricker, 2011). Hospital and emergency room services, as well as a loss of productivity, constitute a large component of costs associated with late Lyme disease (Zhang et al., 2006). The average costs incurred by patients for a typical case of Lyme disease is estimated to be between $161 to $205 in direct medical treatment costs, if diagnosed in the early stages. More serious sequelae, due to early and late disseminated disease, can result in complications that cost from $1,804 to $5,444 per patient in direct medical costs during the first year (Meltzer, Dennis, & Orloski, 1999; Fix, Strickland, & Grant, 1998).

Although the overall number of reported Lyme disease cases has increased since 1991 when reporting first began, several endemic states, including Maryland, have reported a decrease in cases between 2008 and 2011. This reduction in reported cases of Lyme disease is still not well understood – a change in case definition in January 2008 certainly confounds interpretation - but the collective impact of control and prevention practices in high prevalent areas is a possible factor as well. Inconsistencies created through passive surveillance systems remain a major hurdle in interpreting disease trends as not every case of Lyme disease is reported by a medical provider to the county health department. Underreporting is more likely to occur in highly endemic areas depending on the legal mandate and surveillance practices of the state or local health department (Centers for Disease Control and Prevention, January 11, 2013). Lyme disease was underreported by 10 to 12 fold between 1992 and 1993 (Coyle et al., 1996) and recent studies by CDC suggest the total number of people diagnosed with Lyme disease is roughly 10 times higher than the yearly reported number (Kuehn, 2013).

Climatic and ecological changes in tick and host species habitat have likely influenced changes in the geo-temporal risk of populations (Leger, Vourc'h, Vial, Chevillon, & McCoy,

2013). Seasonal fluctuations and prolonged abnormal weather patterns in various parts of the United States prior, during, and after 2008 may have influenced the transmission efficiency of *B. burgdorferi* among tick and host species resulting in changes in the number of reported cases of Lyme disease. Other studies have shown that the presence of certain bacteria produce antifreeze glycoprotein inside ticks increasing the cold tolerance and survival of *I. scapularis* during the winter (Neelakanta, Sultana, Fish, Anderson, & Fikrig, 2010) presumably resulting in a higher density of ticks over time.

The complex dynamic between *B. burgdorferi*, environment, host and vector species, and disease outcome warrants a greater understanding of the available public and private stakeholders that could be expanded or modified to improve the effectiveness and efficiency of Lyme disease control. An exploratory internet web search on 'Lyme disease' produces an extensive list of public and private sector organizations associated with Lyme disease prevention. However, the actual frequency and spatiotemporal coverage of specific tick-control and Lyme disease prevention practices in high risk areas is not well documented, compromising the ability of local authorities to understand the potential role of the public and private sector.

This study measured the diffusion of tick control and Lyme disease prevention strategies implemented during 2009-2014 in high prevalent counties of Maryland. While key variables were identified that influenced the public and private sectors involvement in Lyme disease control and prevention strategies, this study was not designed to establish causation between intervention(s) and disease outcome. Instead, this study measured the range and frequency of tick control and Lyme disease prevention activities implemented by public and private organizations. Study results were synthesized from qualitative and quantitative data to inform future strategies and coordination mechanisms for the control and prevention of Lyme disease.

Background

Lyme disease in North America.

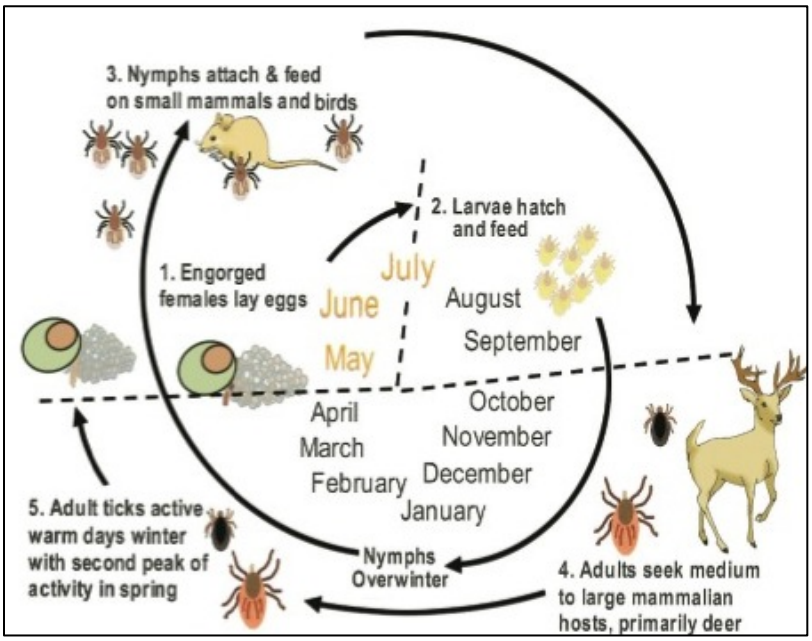
In 1776, Yale University researchers described a clustering of undiagnosed illness, suspected to be some kind of juvenile rheumatoid arthritis, in and around three towns in Connecticut, including the towns Lyme and Old Lyme. The condition was called “Lyme disease arthritis” (Steere et al. 1977). Presence of an EM rash among some of the patients led to the recognition that cases in the United States were of the same tick-borne condition known in Europe. Prior to 1976, *B. burgdorferi sensu lato* infections were known as tick-borne meningopolyneuritis, Garin-Bujadoux syndrome, Bannwarth syndrome, Afzelius' disease, Montauk Knee or sheep tick fever (Bolognia, Jorizzo, & Rapini, 2007). The introduction of *B. burgdorferi* to the United States is uncertain, however examination of preserved museum specimens has found *Borrelia* DNA in an infected mouse from Cape Cod circa 1894 (Drymon, 2008). Recent studies suggest that Lyme disease has been present in North America for thousands of years and has followed the migration of early settlers from the Northeast to the Midwest in the early 19th century (Hoen, et al., 2009). The *Borrelia burgdorferi* spirochete is named in honor of Willy Burgdorfer who is credited with identifying spirochetes from patients with Lyme disease as identical to spirochetes isolated in ticks (Burgdorfer, Barbour, Hayes, Benach, Grunwaldt, & Davis, 1982).

Transmission of Lyme disease

Transmission of *B. burgdorferi* closely follows the 2-year life cycle of the black-legged tick, *I. scapularis* and *I. pacificus*, the primary enzootic vector and bridging vector to humans in the United States (R. J. Eisen, Piesman, Zielinski-Gutierrez, & Eisen, 2012). The distribution of *I. scapularis* and *I. pacificus* encompasses areas of high reported incidence of Lyme disease and defines potential areas for disease emergence. Areas with a high density of infected nymphs from *scapularis* and *I. pacificus* are significantly correlated with human

incidence of Lyme disease, particularly in high-prevalent areas (Pepin et al., 2012). The black-legged tick is a three host tick; each feeding stage (larva, nymph and adult) requires one vertebrate blood meal for its development. When the tick attaches to a suitable host, it inserts its mouthparts and begins to suck the host's blood. The tick's saliva travels into the wound to keep the blood from clotting and carries infectious material into the wound. Host species like the white-footed mouse (*Peromyscus leucopus*), are effective reservoirs for *B. burgdorferi* compared to white-tailed deer (*Odocoileus virginianus*); a higher proportion of ticks become infected after taking a bloodmeal from an infected mouse verses an infected deer. On the other hand, white-tailed deer are important hosts for sustaining black-legged tick populations and therefore influence the intensity of disease transmission by supporting the amplification of host seeking ticks feeding on white-footed mice and other reservoir species (Mather, Wilson, Moore, Ribeiro, & Spielman, 1989). Ticks that are attached to a suitable host for more than 24-36 hours are more likely to transmit infection to that host (Alao & Decker, 2012) .

Figure 1: Tick Life Cycle



Source: Centers for Disease Control and Prevention

The life cycle of a black-legged tick, depicted in Figure 1, starts from a single batch of eggs deposited in the leaf litter in early spring by a previously blood fed female tick. When eggs hatch in early to mid-summer, six-legged larvae emerge and seek a suitable host, such as the white-footed mouse or other small mammals or lizards (Anderson & Magnarelli, 1980).

After taking a bloodmeal over a 3-5 day period, larvae drop to the leaf litter or host den to digest the blood, stimulating the molting process to become eight legged nymphs before overwintering. In early spring of the second year of life, nymphs will take a second bloodmeal, usually from another small mammalian, avian, or human host before molting again. The engorged nymph drops to the leaf litter again to continue its development into an adult. In late to early fall of the same year the adult ticks begin to quest for a third host, typically larger mammals like the white-tailed deer. Adults will feed on a suitable host for 5-7 days – during which time mating also occurs. Engorged adult ticks will find protection in the leaf litter before emerging in early spring to ovideposit eggs, but can remain active through the winter on days when the ground and ambient temperatures are above freezing. Incidence of new cases of Lyme disease in the Northeast and Midwest are greatest during the months of May through July when nymphs are most abundant and difficult to detect by human hosts (Piesman, 1989).

Lyme disease surveillance and reporting

Five major categories of TBDs are under national surveillance in the United States, as part of the National Notifiable Disease Surveillance System (NNDSS), including Lyme disease, Ehrlichiosis/Anaplasmosis, Babesiosis, Spotted Fever Rickettsiosis, and Arbovirus infection. Although Tularemia is a notifiable disease that can be spread through the bite of ticks, it is not categorized as a TBD since the infection can also be transmitted by eating or drinking contaminated food or water, handling animal carcasses, or through the bite of deerflies and other insects. Three additional TBDs are recognized as occurring in the United

States but are not notifiable, including Southern Tick-Associated Rash Illness (STARI), Tick-Borne Relapsing Fever, and Colorado Tick Fever (Centers for Disease Control and Prevention, 2012). In addition to transmitting Lyme disease, *I. scapularis* and *I. pacificus* are known tick vectors for Anaplasmosis, Babesiosis, and Powassan Encephalitis.

The Council of State and Territorial Epidemiologists (CSTE) has provided a surveillance case definition of Lyme disease since 1995, with subsequent modifications in the definition in 1996, 2008, and 2011. The surveillance case definition developed for national reporting of Lyme disease, however, is not intended for clinical diagnosis. Clinical diagnosis is based on signs and symptoms and a history of possible exposure to infected blacklegged tick. Differences between surveillance and clinical diagnosis continue to generate debate among physicians and infectious disease experts on how individual cases should be classified and treated. Surveillance criteria are intended to be far stricter than what would be required for treatment; however surveillance systems that are unable to detect or report on cases that meet the stricter criteria underestimate risk and undermine control and prevention. The 2011 case guideline for surveillance recognizes three classifications of Lyme disease: confirmed, probable, and suspected (Table 1) which are captured on state case reporting forms. Probable cases were not reported prior to 2008. Changes in the case definition in 2011 also clarified the definition of a qualified laboratory assay.

Table 1: Lyme disease case classification for surveillance

Classification	Definition
Confirmed	a) A physician diagnosed case of EM[1] with a known exposure (contact with potential tick habitats in a county in which Lyme disease is endemic less than or equal to 30 days before onset of EM). A history of tick bite is not required; **or** b) A physician diagnosed case of EM with laboratory evidence[2] of infection if there is no known exposure (a positive culture for *B. burgdorferi*, a positive two-tier test, a single-tier IgG immunoblot seropositivity, or a positive colony stimulating factor (CSF) antibody by Enzyme Immunoassay or Immunoflurescence Assay); **or** c) A physician diagnosed case of EM with at least one late manifestation[3] (musculoskeletal, nervous, or cardiovascular) with laboratory evidence of infection.

[1] CDC recommends for the purposes of surveillance, EM is defined as a skin lesion that typically begins as a red macule or papule and expands over a period of days to weeks to form a large round lesion, often with partial central clearing. A single primary lesion must reach greater than or equal to 5 cm in size across its largest diameter. Secondary lesions may occur. Clinical diagnosis for treatment may include a far more varied presentation of dermatitis.

[2] CDC recommends for the purposes of surveillance, the definition of a qualified laboratory essay is one of the following: 1) Positive Culture for *B.burgdorferi*; 2) two-tier testing interpreted using established criteria, where: a) Positive IgM is sufficient only when ≤ 30 days from symptom onset, b) Positive IgG is sufficient at any point during illness; 3) Single-tier IgG immunoblot seropositivity using established criteria; or 4) CSF antibody positive for *B.burgdorferi* by Enyme Immunoassay or Immunoflurescence Assay, when the titer is higher than it was in serum.

[3] CDC recommends for the purposes of surveillance, late manifestations include any of the following when an alternate explanation is not found: 1) Recurrent, brief attacks (weeks or months) of objective joint swelling in one or a few joints, sometimes followed by chronic arthritis in one or a few joints; 2) Any of the following, alone or in combination: lymphocytic meningitis; cranial neuritis, particularly facial palsy (may be bilateral); radiculoneuropathy; or, rarely, encephalomyelitis confirmed by demonstration of higher antibody production against *B. burgdorferi* in cerebrospinal fluid than in serum; 3) Acute onset of high-grade (2nd-degree or 3rd-degree) atrioventricular conduction defects that resolve in days to weeks and are sometimes associated with mycocarditis.

Classification	Definition
Probable	Any other case of physician-diagnosed Lyme disease that has laboratory evidence of infection
Suspected	a) A physician diagnosed case of EM where there is no known exposure and no laboratory evidence of infection; **or** b) A physician diagnosed case of EM with laboratory evidence of infection but no clinical information available (e.g. a laboratory report).

Source: CSTE Position Statement Number: 10-ID-06. Lyme disease (Borrelia burgdorferi)

Lyme disease is categorized as early localized infection, early disseminated infection, or late persistent infection. Early cutaneous manifestations may involve an expanding annular lesion around the original tick bite, called erythema migrans, and is usually sufficient for diagnosis and treatment, however the rash only appears in an estimated 50% -70% of patients (Alao & Decker, 2012). Because misdiagnosis is common at early stages of the disease, many patients endure an extended period of illness before receiving appropriate treatment. Additional co-infections that can be transmitted by *I. scapularis* and *I. pacificus* often complicate diagnosis.

Treatment guidelines recommended by CDC were developed by the Infectious Disease Society of America (IDSA) (Wormser et al., 2006). In Maryland, Lyme disease is diagnosed and treated based on signs and symptoms and history of being exposed to infected blacklegged ticks. Serologic testing may also be conducted on suspected cases that do not present typical clinical symptoms. When serological testing is warranted, CDC recommends using the two-tiered protocol, even though sensitivity of the protocol is estimated to be 64% in early testing (Steere, McHugh, Damle, & Sikand, 2008) .

The role of federal and state health agencies

Although the CDC is one of the lead agencies on the prevention of Lyme disease and other TBDs in the United States, state and county health departments often bear the responsibility for the implementation and coordination of disease control and prevention activities. Ultimately, the immediate decisions on control and prevention of TBDs are made at the family or individual level (Piesman & Eisen, 2008), but are also manifested through collective action by public and private sector stakeholders.

CDC's Lyme disease prevention and control program provides science-based education, research, and service, through partners within the National Institutes of Health and other federal agencies, state and local health departments, and other non-federal organizations. CDC supports national surveillance, epidemiologic response, field and laboratory research, consultation, and educational activities. CDC also funds collaborative studies on community-based prevention methods, improved diagnosis and understanding of pathogenesis, tick ecology, and development and testing of new tools and methods for tick control (Mead, 2004). A primary goal emphasized by CDC is to work with Lyme disease endemic communities to develop an Integrated Pest Management (IPM) approach, which includes a wide assortment of practical tick control strategies. IPM employs environmental management, biological and chemical control of ticks, and enhanced personal protection through tick avoidance and other measures to prevent Lyme disease (Mead, 2004). The goal of an IPM approach is “to reduce human illness and associated economic costs while minimizing potential environmental impacts” (Beard & Strickman, 2014).

The Public health system in Maryland is supported by the Department of Health and Mental Hygiene (DHMH) and 24 local health departments, including 23 counties and Baltimore City. The DHMH has three major divisions - Public Health Services, Behavioral Health and Disabilities, and Health Care Financing. The Public Health Services Division oversees several public services including infectious disease and environmental health

concerns, many of which are covered under the Prevention and Health Promotion Administration and the Infectious Disease and Environmental Health Administration (IDEHA). These administrative units provide public health services through partnerships with local health departments and public and private sector stakeholders including the prevention and control of infectious diseases, investigation of disease outbreaks, and protection from food related and environmental health hazards.

Within the Maryland Public Health Service Division, the Center for Zoonotic and Vector-borne Diseases (CZVD) monitors, investigates, and reports on diseases that can be transmitted between animals and humans, including Lyme disease, rabies, West Nile Virus, and avian influenza. The Center provides education and training to local health department personnel and general information to the public about zoonotic diseases. Educational materials and resources highlight research, educational initiatives, and special projects involving ticks, mosquitoes, and other disease-carrying vectors. In Maryland, mosquito control is operated by the Maryland Department of Agriculture, which also participates in tick identification[4].

Tick-control and Lyme disease prevention

Most references to 'Lyme disease prevention' focus on personal preventative measures - behavior change strategies that limit contact with tick species - as a primary intervention to reduce transmission of *B. burgdorferi* . Lyme disease prevention is also used in reference to vaccine development, prophylactic treatment, and the proper removal of attached ticks in less than 24 - 36 hours, as proactive measures to reduce the probability of infection after being bitten by an infected tick. Tick-control strategies, on the other hand, may incorporate components of Lyme disease prevention, but are specifically related to activities aimed at reducing the infectivity or density of tick vectors in a given area. The primary objective of tick control for Lyme disease is to actively reduce the quantity, range,

[4] http://www.mda.state.md.us/plants-pests/Documents/tickid.pdf

and infectivity rate of *I. scapularis* and *I. pacificus*, as well as the infection rate in host species.

One of the most widely cited resources by federal and state agencies on the control and prevention of TBDs from the 2004 Tick Management Handbook developed by Kirby C. Stafford II from the Connecticut Agricultural Experiment Station (K. C. Stafford, 2004). The Handbook, funded by the CDC and The Connecticut Agricultural Experiment Station, provides details on personal protection, integrated tick management, area-wide chemical control of ticks, and organic land care practices. Many of the recommended personal prevention activities are summarized on the CDC website: www.cdc.gov/lyme. The CDC website and the 2004 Tick Management Handbook encourage people to reduce exposure to ticks and to be extra vigilant during warmer months (April-September) when ticks are more active by considering the following activities:

1. Limit exposure to ticks:
    a. *Avoid wooded and bushy areas with high grass and leaf litter.*
    b. *Walk in the center of trails.*
2. Adopt Personal protective measures:
    a. *Use repellents that contain 20 to 30% DEET (N, N-diethyl-m-toluamide) on exposed skin and clothing for protection.*
    b. *Wear light-colored clothing with long pants tucked into socks to make ticks easier to detect and keep them on the outside of the clothes. Use clothing that is pre-treated with permethrin when possible. Treat clothing and gear, such as boots, pants, socks and tents with products containing 0.5% permethrin.*

c. *For pet owners, apply an appropriate tick repellent to prevent bites[5] or an acaricide (Fipronil, Pyrethroids, Amitraz) to kill ticks on contact or when they take a blood meal.*

d. *Conduct a full-body tick check using a hand-held or full-length mirror to view all parts of your body upon return from tick-infested areas. Parents should check their children for ticks under the arms, in and around the ears, inside the belly button, behind the knees, between the legs, around the waist, and especially in their hair. Tick bites on dogs and outdoor pets may be harder to detect and should be checked for ticks daily. Examine outdoor gear; ticks can ride into the home on clothing, pets, and day packs.*

e. *Bathe or shower as soon as possible after coming indoors (preferably within two hours) to wash off and more easily find ticks.*

f. *Remove ticks right away – use a removal device or a plain set of fine-tipped tweezers. Pull upward with steady, even pressure. Don't twist or jerk the tick which may cause the mouth-parts to break off and remain in the skin. If this happens, remove the mouth-parts with tweezers. If unable to remove the mouth easily with clean tweezers, leave it alone and let the skin heal. After removing the tick, thoroughly clean the bite area and hands with rubbing alcohol, an iodine scrub, or soap and water.*

g. *Dispose of a live tick by submersing it in alcohol, placing it in a sealed bag/container, wrapping it tightly in tape, or flushing it down the toilet[6]. Never crush a tick with your fingers.*

---

[5] CDC suggests that a disadvantage of using a repellent on pets is that while it may prevent bite wounds and possible infections, it also will not reduce the number of ticks in the environment (doesn't kill the tick). Therefore the use of arcaricides on dogs to reduce the number of ticks could be considered a tick control strategy.

[6] Maryland Department of Agriculture's tick identification program relies on passive submission of specimens. Disposal of ticks may discard additional entomologic evidence if human diagnostic tests are inconclusive. In general, CDC considers testing of individual ticks as not useful because positive tests only confirm that the tick contains disease-causing organisms – it does not necessarily mean that person bitten has been infected. CDC also warns that people infected by a tick may delay treatment if waiting for results of the tick test – individuals are

h. *Tumble clothes in a dryer on high heat for an hour to kill remaining ticks.*

i. *Reduce tick habitat from yard by making your yard less attractive to ticks.*

   i. *Clear tall grasses and brush around homes and at the edge of lawns.*

   ii. *Place a 3-ft wide barrier of wood chips or gravel between lawns and wooded areas and around patios and play equipment to restrict tick migration into recreational areas.*

   iii. *Mow the lawn frequently and keep leaves raked.*

   iv. *Stack wood neatly and in a dry area (discourages rodents that ticks feed on).*

   v. *Keep playground equipment, decks, and patios away from yard edges and trees and place them in a sunny location, if possible.*

   vi. *Remove any old furniture, mattresses, or trash from the yard that may give ticks a place to hide.*

3. Apply area-wide acaricides around residential property:

   a. *Apply a single springtime application of an acaracide (tick pesticide), such as bifenthin, to reduce the number of ticks in your yard. Consider using a professional pesticide company*[7] *and check with local health officials about the best time to apply acaricide in your area. Identify rules and regulations related to pesticide application on residential properties (Environmental Protection Agency and your state determine the availability of pesticides).*

---

more likely to develop symptoms before results of the tick test are available. A negative test may lead to false assurances if the person is bitten by more than one disease carrying tick. The overall recommendation to dispose of ticks however does not suggest that standardized tick monitoring and testing is not warranted if part of larger risk-mapping activities.

[7] The distinction between private homeowners and professional pest companies in applying an acaricide is important when considering messaging and monitoring the collective impact of area-wide acaricides.

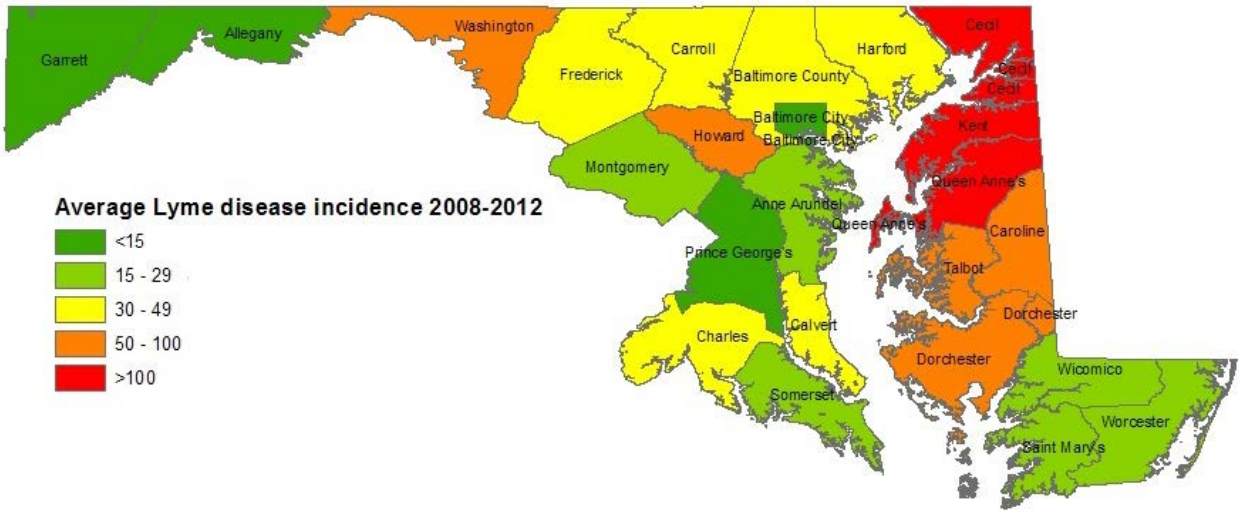
Table 2: Summary of tick control and Lyme disease prevention methods

Category	Objective	Strategy	Activity
Lyme Disease Prevention	Modify human behavior to reduce exposure to ticks and prevent transmission by prompt removal of attached ticks.	Limit human exposure to spatiotemporal risks	Raise awareness and avoidance of high-risk habitats during peak transmission season
			Conduct routine tick monitoring (tick drags and tick identification)
		Promotion of Personal Protective Measures	Conduct regular tick checks (remove ticks properly < 24 hrs. after attachment)
			Wear appropriate/protective clothing (including permethrin impregnated/treated clothing)
			Apply repellents (synthetic or natural based products) on skin
			Apply acaricides around residential properties
	Prevent Lyme disease by vaccination against *B. burgdorferi* or prophylactic treatment after bite.	Vaccination	Human immunization against Lyme disease (currently not available)
		Prophylactic treatment	Administer appropriate antibiotic soon after tick bite
Tick Control / Disease Agent Reduction	Reduce overall tick density.	Area-wide application of acaricides (commercial or public)	Application of synthetic pyrethroids (e.g., cyfluthrin, permethrin, and deltamethrin)
			Application of entomopathogenic fungal agents (e.g., *Metarbizium anisoplaie*)
			Application of Natural Organic Compounds (e.g. nootkatone and Carvacrol)
			Use of soaps and desiccants
		Host-targeted application of acaricides	Application of acaricides on rodent host species (e.g., bait boxes, permethrin-treated cotton balls)
			Application acaricides on dogs, or other domesticated animals
			Application of acaricides to deer host species (e.g., 4-poster device)
		Landscape and vegetation management	Removal of leaf litter and brush
			Bordering (e.g. cedar mulch, transitional zones)
		Wildlife management	Wildlife Fencing
			Host reduction/elimination (e.g., hunting, sterilization)
		Biologic approaches	Parasitic nematodes, parasitic wasp, Guinea Fowl, etc.
	Lower the prevalence of *B. burgdorferi* infection in reservoir hosts and/or host-seeking ticks.	Host vaccination	Oral OspA vaccine for rodents
			Lyme vaccine for household pets
		Host treatment	Oral bait formulated with doxycycline for rodents

Tick control and Lyme disease prevention strategies have been more recently summarized in peer-review journals (Clark & Hu, 2008; R. J. Eisen, Piesman, Zielinski-Gutierrez, & Eisen, 2012; Piesman & Eisen, 2008; T. L. Schulze et al., 2006). Table 2 categorizes the major control and prevention strategies and activities described in the peer-review literature and CDC websites.

Lyme disease in Maryland

Figure 2: Average incidence of Lyme disease per 100,000 according to surveillance reports in Maryland, 2008-2012



Data source: http://phpa.dhmh.maryland.gov/SitePages/disease-conditions-count-rates.aspx

Between 2005 and 2007 the number of confirmed Lyme disease cases (surveillance definition) reported in Maryland increased from 1,235 to 2,576, a 109% increase. Between 2008 and 2011, however, the annual incidence rates (cases per 100,000 people per year) began decreasing; 39.4, 35.5, 28.0 and 23.2 for the years 2008, 2009, 2010, and 2011, respectively. Between 2011 and 2012 incidence rose again from 23.2 to 28.0, or a 133%

increase in the number of cases reported from 706 cases to 1,650 cases between 2011 and 2012. Among Maryland's 23 counties, eight counties reported an average incidence of Lyme disease more than 50 cases per 100,000 from 2008 to 2012, including: Kent, Caroline, Queen Anne's, Cecil, Talbot, Howard, Dorchester, and Washington (Figure 2).

Importance and Rational

Evidence suggests that tick species are expanding in geographical range and density in the United States with the potential of carrying *B. burgdorferi* and other infections to previous non-endemic areas (Centers for Disease Control and Prevention, May 13, 2011). Given the challenges in the diagnosis and treatment of Lyme disease and the absence of a reliable human vaccine, a comprehensive and practical approach is needed to measure the frequency and spatiotemporal coverage of practices and to evaluate the role of the public and private sector in Lyme disease control and prevention efforts.

Tick density and infection rates can vary dramatically from county to county within a state (Centers for Disease Control and Prevention, June 15, 2007), and change over time as epidemiologic patterns shift within the complex host-tick-environment relationship. Disease modeling has identified certain geographic distribution patterns influenced by place of residence, density of infected nymphs, vegetation distribution, and population density that are predictive of high risk areas for human infection with *B. burgdorferi* (Diuk-Wasser et al., 2012; R. J. Eisen, Lane, Fritz, & Eisen, 2006; Frank, Fix, Pena, & Strickland, 2002; Glass et al., 1995; LoGiudice, Ostfeld, Schmidt, & Keesing, 2003; Nicholson & Mather, 1996; Ostfeld et al., 2001). Consequently, tick-control and Lyme disease prevention practices are often not uniformly implemented across a state.

Given a limited number of resources invested in tick control, states and counties must exploit opportunities to enhance and expand control practices and/or identify barriers that have prevented prevention and control practices from occurring in endemic

communities. The major challenges of controlling TBDs are unlikely to be solved by a panacea or silver-bullet approach. For many medical professionals the development and introduction of an effective new vaccine remains the best solution. Instead, evidence-supported practices need to be layered, multipronged, and take into consideration cultural, political, economic, and environmental factors that affect the long-term efficiency and effectiveness of disease control programming. Establishing a well-defined TBD decision support system (TBDDSS) managed at the state or county level is an important step to effectively use spatiotemporal epidemiologic and entomologic data to encourage prevention seeking behavior and to encourage tick-control activities during optimal times during the year. In addition, leadership at the federal, state, and county levels must remain aware of potential inequities across high prevalent areas and improve the diffusion of evidence based tick-control and Lyme disease prevention practices, as appropriate.

CHAPTER 2: LITERATURE REVIEW

Since the publication of the Connecticut Agricultural Experiment Station's Tick Management Handbook (2004), the peer-reviewed literature published between February 2004 and February 2012 has provided a range of tick control and Lyme disease prevention activities implemented in the United States.

Search Terms and Criteria

A systematic search of key words was performed using PubMed and BIOSIS Previews (Table 3). Although PubMed comprises over 21 million citations for biomedical literature from MEDLINE, tick control methods are often multi-disciplinary and captured in journals not included in PubMed searches. BIOSIS Previews therefore served as an additional source of journals within the biological sciences.

Table 3: PubMEd and BIOSIS Previews

ALL Searches limited to English, Publication date of 01/01/2004 – 2/29/2012 and INCLUDED:	
Concept	**Key words, search terms**
Primary Lyme vector species - *Ixodes scapularis* or *Ixodes pacificus*	Tick OR Ixodes
AND	
Lyme disease, *borreliosis*, *Borrelia burgdorferi*	Lyme
AND	
Tick Control Activities	Control
AND	
Range	United States
AND	
Date	01/01/2004 – 02/29/2012

Articles published between 2004-2012 (February) that describe control and prevention activities for *Ixodes spp.* in the United States were reviewed and screened to assess which field-based activities were specifically implemented for the prevention of Lyme disease

and/or aimed at reducing the quantity, range, or infectivity of ticks. When available, efficacy of activities were recorded and analyzed. Articles that presented results of a meta-analysis, or summarized previous work already captured within the literature search, were considered duplicative and not included. Vector control activities that met the following criteria were included in the final analysis:

1. Activity was primarily field-based (outside of a laboratory setting).
2. Intended purpose of activity was to reduce the quantity of ticks, range of ticks and/or infectivity rate of ticks;
3. Vectors targeted by activity inclusive of *I. scapularis* and/or *I. pacificus* ticks as a strategy to reduce risk of Lyme disease transmission;
4. Abstract provided implementation basis and geographical area targeted.

Process for reviewing articles

All identified articles were recorded on a summary sheet, including pertinent information on control and prevention activities, study design, targeted vector, targeted diseases, targeted geographic area, implementation basis, and general findings. Abstracts were previewed and evaluated based on inclusion criteria; articles and reports not meeting all specified criteria were excluded.

Literature Review Findings

The duration of which control and prevention activities were implemented and studied ranged from 5 months to 7 years. Studies that involved the United States Department of Agriculture- Agricultural Research Service's (USDA-ARS) patented 4-Poster treatment device for deer were implemented for five continuous years on average. The longest sustained tick-control intervention was 7 years, documented in the evaluation of annual community-led hunts of white-tailed deer to control *I. scapularis* nymphs in one community in Mumford Cove, Connecticut (Garnett, Connally, Stafford, & Cartter, 2011).

Depending on the specific control tool, the applied frequency of control strategies over the course of a year varied from a single application to weekly, biweekly, or monthly application, with some interventions indiscriminately being applied over the duration of the study period. In general, geographical areas targeted by activities were highly focalized within a State and were not applied uniformly across all high-risk areas for Lyme disease.

Human exposure to spatiotemporal risk patterns

A single study considered the dissemination of primary prevention information to passengers on ferryboats going from Hyannis, MA to Nantucket Island, MA, during three consecutive summers in order to encourage people to avoid high-risk tick habitats (Daltroy et al., 2007). The study found that there were lower rates of tick borne infection among participants receiving education compared with control participants, especially visitors who stayed on Nantucket Island for more than 2 weeks. Overall, passengers who were informed about the risk of TBDs on the island were significantly more likely to take precautions (use repellent, protective clothing, limit time in tick areas) and check themselves for ticks.

Personal protection measures

Four studies looked at the impact of adopting one or more personal protection measures to prevent tick bites, or to reduce the likelihood of transmission after being bitten, by removing the attached tick within 24 hours, including: conducting regular tick checks, wearing protective clothing, wearing permethrin impregnated clothing, and applying repellents on clothes or skin (Connally et al., 2009; Daltroy et al., 2007; Vaughn & Meshnick, 2011; Vazquez et al., 2008). Performing regular tick checks (i.e., inspecting body parts for ticks), specifically after an individual was outdoors in a woodsy area, reduced the risk of Lyme disease as did wearing protective clothing (Connally et al., 2009; Daltroy et al., 2007). The authors note that during spring and early summer, when larvae and nymphs are more abundant, detection of ticks on the body becomes more challenging due

to their size. In a study conducted by Vaughn and Meshnick clothing was impregnated with permethrin, which does not repel ticks but kills them upon contact. People who wore the impregnated clothing reduced the incidence of tick bites compared with controls (Vaughn & Meshnick, 2011). The use of repellents on clothes or skin was investigated in 2 studies (Daltroy et al., 2007; Vazquez et al., 2008). These studies concluded that there was a greater adoption of personal protection behaviors, including the use of repellents, in people without Lyme disease, suggesting that these behaviors are protective against Lyme disease.

Prophylactic treatment

A single 200-mg dose of doxycycline given within 72 hours after an *I. scapularis* tick bite was recommended for patients based on a study conducted prior to 2004 (Nadelman et al., 2001). The study suggests that a single 200 mg dose of doxycycline prevented the development of cutaneous EM. As a follow-up to this study Elizabeth Maloney conducted a review of the antibiotic prophylaxis recommendation for Lyme disease and the evidence supporting it. Her conclusion is based on limited evidence but suggested that physicians may want to consider alternative recommendations to improve efficacy of antibiotic prophylaxis in preventing clinical signs of Lyme disease, including the administering of 100-mg dose of doxycycline twice daily for 10 to 20 days (Maloney, 2011). Current recommendations from the Infectious Diseases Society of America (IDSA) are that a single dose of doxycycline should only be prescribed if all of the following exists:

> *the attached tick can be reliably identified as an adult or nymphal I. scapularis tick that is estimated to have been attached for ⩾36 h on the basis of the degree of engorgement of the tick with blood or of certainty about the time of exposure to the tick; (b) prophylaxis can be started within 72 h of the time that the tick was removed; (c) ecologic information indicates that the local rate of infection of these ticks with B. burgdorferi is ⩾20%;* and *(d) doxycycline treatment is not contraindicated* (Wormser et al., 2006).

Concerns over IDSA guideline on prophylactic treatment stress that the average physician would not have basic training on tick biology or information about local rates of infection among tick species. In addition previous studies demonstrate that early administration of

antibiotics only block seroconversion to *B. burgdoreferi* antibodies without eliminating infection (Volkman, 2007) .

Area-wide acaricides

Three studies documented the use of bio-chemical acaricides applied with sprayers over large areas. Bio-chemical acaricides are often categorized separately from synthetically derived pesticides. The bio-chemicals used in the studies included applications of plant-derived acaricides, including nootkatone, carvacrol, *Beauveria bassiana*, and *Metarhizium anisopliae* (Metschnikoff) Sorokin strain F52 for the control of *I. scapularis* nymphs (Dolan et al., 2009; Jordan, Dolan, Piesman, & Schulze, 2011; K. C. Stafford 3rd & Allan, 2010). All three studies showed significant reductions in nymphal tick abundance as applied by trained spray operators to large wooded areas.

Two additional studies explored area-wide spraying of chemical acaricides on domestic properties as part of a larger evaluation of Lyme disease prevention behaviors (Connally et al., 2009; Vazquez et al., 2008). Both case-control studies showed that spraying acaricides routinely on one's property did not differ significantly for case-patients and matched controls; i.e. the application of commercial available acaricides by individual families did not significantly protect individuals against Lyme disease. The two studies suggest that even with longer lasting commercially available chemicals, domestic application of acaricides by individual households does not significantly protect against Lyme disease. The lack of a protective effect however may not be related to the chemicals themselves, but issues with application of chemicals: when, where, and how chemical acaricides are applied.

Prior to 2004, several studies showed that area-wide spraying of acaricides to control tick populations resulted in significant reductions (Curran, Fish, & Piesman, 1993; Patrican & Allan, 1995; T. L. Schulze, Taylor, Vasvary, Simmons, & Jordan, 1992). Area-wide application of chemicals, however, is generally not widely accepted by communities due to

public concern over adverse environmental effects, toxicity, and impact on non-targeted organisms (Golaine, 2011). Because of this concern, emphasis on plant derived acaricides, or bio-chemicals, as well as integrated control strategies are being more widely promoted.

Host-targeted approaches

Concerns over the broad use of pesticides has driven support for host-targeted application of acaricides, such as the large scale multi-year USDA supported Northeast Area-wide Tick Control Project (NEATCP), a five year large-scale cooperative demonstration project of the USDA—ARS patented 4-Poster tick control technology, which was promoted as an efficacious, economical, safe, and environment-friendly alternative to area-wide spraying of acaricide to control tick species (Pound et al., 2009). The majority of tick control activities identified by the literature review involved the use of a passive device or material to topically apply insecticide to targeted host species. Of the eight articles that described this approach, six of the studies were supported directly or influenced by NEATCP. Research locations were independently set up in five states (Connecticut, Maryland, New Jersey, New York, and Rhode Island) to study the extent that tick-vector control could be achieved (Pound et al., 2009). By the sixth treatment year, the NEATCP effectively reduced the relative density of *I. scapularis* nymphs by 71% on an average size treatment site (5.14 km^2), corresponding to a 71% lower relative entomologic risk index for acquiring Lyme disease (Brei et al., 2009). An additional follow-on period was conducted on Gibson Island, Maryland, using a similar device but supported by a private cooperation and showed that host-seeking nymphs remained at consistently low levels on the island in spite of 40% fewer 4-Posters and an increase in deer density during the follow-on period (Carroll, Pound, Miller, & Kramer, 2009).

The 7th study involving topical application of insecticides to host species investigated the application of rodent-targeted acaricide (fipronil) through bait boxes to control immature *I. scapularis* ticks. The findings of this study showed that modified commercial bait boxes

were effective as an acaricide delivery method for reducing nymphal and larval tick infestations on white-footed mice. Abundance of questing *I. scapularis* adults on treated properties was also reduced compared with untreated sites (Dolan et al., 2004).

The last study focused on the use of M. anisopliae-treated nesting material (entomopathogenic fungus) placed in artificial nestboxes to control larval and nymphal *I. scapularis* ticks (Hornbostel, Ostfeld, & Benjamin, 2005). Entomopathogenic fungi is a biocide and considered separately from synthetic based chemical insecticides. The delivery mechanism to host species can be the same as with more commonly used area-wide acaricides, however, in this study the acaricide was passively applied to rodent species. The study found that treated nesting material did not effectively control *I. scapularis* over a relatively large spatial area but exhibited modest control in smaller, treatment-localized areas.

Landscape and Vegetation management

Landscape and vegetation management was not well captured in the literature review. A study investigating various landscape management strategies only found fencing to be protective against Lyme disease (Connally et al., 2009). In a separate study, results showed that a prescribed controlled-fire conducted in a highly endemic area of California had no significant difference on the number of immature *I. pacificus* ticks per animal trapped at burn site and no significant difference in the number of adult ticks collected postburn per site per month for *I. pacificus* compared with control sites (Padgett, Casher, Stephens, & Lane, 2009). Despite a lack of evidence to support the effectiveness of landscape management in the control of ticks, the CDC emphasizes to homeowners to create tick-free borders (barriers/edging), remove leaf litter, clear tall grasses and brush around homes, and to mow lawns frequently.

Wildlife management

Three studies included the culling of white tail deer as a control strategy; however only the complete removal of deer from the study area (Monhegan Island, ME) showed a significant decrease in the number of questing ticks (Rand, Lubelczyk, Holman, Lacombe, & Smith, 2004). Deer hunting in the other two studies did not show a clear decrease in the incidence of Lyme disease compared with control sites (Garnett, Connally, Stafford, & Cartter, 2011; Jordan, Schulze, & Jahn, 2007) . The Monhegan Island study showed a significant decline in the number of questing adults, but only 3 years later and only after observing a sharp increase in questing adult ticks during the last year deer were removed from the island. If the final evaluation of the Monhegan Island study was only based on data collected on the last year deer were removed, then the results may have shown no significant difference. To be able to critique the findings of studies that look at deer management, an established population threshold for deer is needed; i.e., the level that deer populations would need to be reduced and sustained in order to decrease tick populations to a level that no longer poses a significant risk to exposed populations.

Host vaccination

A separate study examined the use of a recombinant antigen, outer surface protein A (OspA), to immunize wild white-footed mice. This study found that the OspA vaccination significantly reduced the prevalence of *B. burgdorferi* in nymphal blacklegged ticks (Tsao et al., 2004). Although the experimental immunization of wild white-footed mice with recombinant antigen of OSpA significantly reduced the prevalence of *B. burgdorferi* in nymphal blacklegged ticks, the immunization of mice required researchers to trap and inject each mouse with the vaccine - a very inefficient distribution mechanism. Additional research is complementing these findings with the development of a lab tested baited oral vaccine for use in reservoir-targeted species in areas at high risk for Lyme disease

(Bhattacharya et al., 2011). This seems very promising for future field-based approaches but still untested.

Host treatment

In one field-based experiment, doxycycline hyclate rodent bait was used to prophylactically treat and protect small-mammal reservoirs from infection (Dolan et al., 2011). The use of the doxycycline hyclate impregnated bait resulted in a significant reduction in infectivity of small mammals and a significant reduction in infection rate of questing nymphal ticks.

Discussion

Excluding meta-analyses and laboratory studies, ten major field-based tick control and Lyme disease prevention activities were described in the literature - this includes limiting human exposure to spatiotemporal risk patterns, adoption of personal protection measures, prophylactic treatment, area-wide application of acaricides, host-targeted application of acaricides, landscape management, vegetation management, wildlife management, host vaccination, and host treatment. Studies involving the use of a human vaccine or biologic control approaches were not identified. The Lyme vaccine developed for use in humans (LYMErix ™) in 1998 was voluntarily removed from the market in 2002 and is not currently available (Poland, 2011); a vaccine however still represents a real and potential tool for prevention.

Prevention and control strategies can be further categorized into one of four major objectives: 1) modify human behavior to reduce exposure to ticks and prevent transmission by prompt removal of attached ticks, 2) prevent Lyme disease by vaccinating population against *B. burgdorferi* (currently not available) or prophylactically treating individuals with antibiotics after a tick bite, 3) reduce overall tick density/prevalence, and 4) lower the prevalence of *B. burgdorferi* infection in reservoir hosts and/or host-seeking ticks. Among

the 22 articles cited (*appendix A*), the major indicators used to evaluate the potential impact on Lyme disease prevalence included:

- Decrease in incidence of tick bites;
- Decrease in prevalence of host-seeking black legged ticks;
- Decrease in prevalence of black-legged ticks on targeted hosts;
- Decrease in infection rate of black-legged ticks infected with *B. burgdorferi*;
- Increased mortality of host-fed blacklegged ticks;
- Decrease in incidence of EM rash;
- Reduced risk in developing Lyme disease;
- Decrease in tick-borne illnesses;

The evidence from the literature review suggests that the density of *I. scapularis* and *I. pacificus* tick species, the prevalence *of B. burgdorferi* infection in reservoir hosts and/or host-seeking ticks, and the incidence of Lyme disease can actively be reduced through available control and prevention strategies. Moreover, several studies identified opportunities to scale-up control and prevention activities beyond the study area, even though the variables that influence the sustainability of Lyme disease control and prevention program have not been sufficiently studied.

Results of these studies still need to be carefully considered given a variety of confounders that may skew interpretation, including ecological changes or events within a region or state that may have significantly countered the benefits of any single independent initiative. In combination with other activities, implementation may become more efficient and the outcome more enhanced. Additionally, where infections occur may differ from where interventions are conducted; i.e., interventions may work but are not reflected in the results because people and animal hosts living in the intervention area are getting actually getting infected in a different area not receiving the intervention. Regardless, it is the

symbiotic and collateral impact of a toolbox approach that is of interest in developing a comprehensive state and county TBDDSS and disrupting transmission of *B. burgdorferi*.

Gaps in Knowledge

The performed literature review does not capture all possible field-based control and prevention strategies implemented during 2004-2012. For example, there is no mention of commercial landscaping and pest control businesses or other non-research based platforms despite the fact that such interventions were most likely occurring during this period. Most of the studies also did not factor a sufficient amount of time to accurately assess the impact on prevalence rates given the two year life cycle of black-legged ticks and the complex patterns between host species and the environment. The activities that were captured, however, demonstrate that reduction of Lyme disease incidence is possible, but requires more than just individual actions. Sustaining long-term area-wide control and prevention activities requires greater public and private involvement and support.

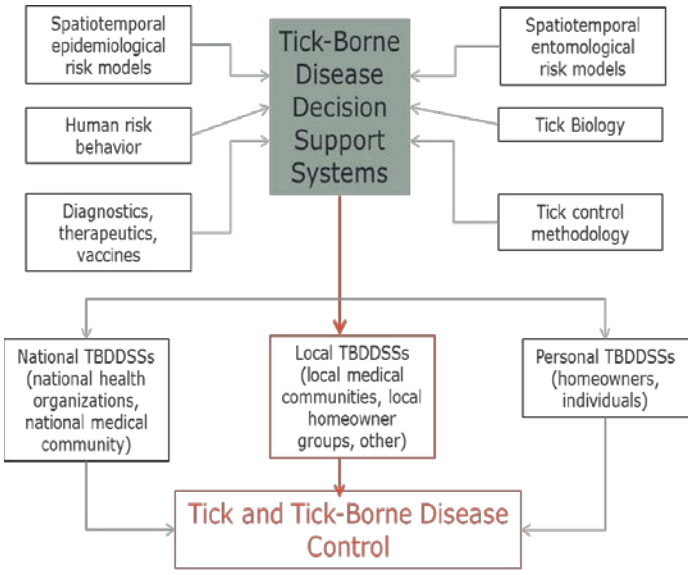
Many of the evaluated activities would have only reach a certain level of efficiency if not co-implemented with other practices; e.g., the culling of deer may potentially have a greater impact on reducing Lyme disease than originally assessed if combined with other practices. Indeed, given a longer implementation period, greater coverage area, and co-implementation of activities, certain activities evaluated to have no significant impact on tick populations or infection rates as a single strategy may have had a more substantial impact as part of a multi-prong approach. Future studies are needed to understand the impact of co-implemented control and prevention strategies. Moreover, greater emphasis is needed on translational research to understand the factors that influence the diffusion of specific practices as part of a TBDDSS.

CHAPTER 3: METHODS

Conceptual Framework

The TBDDSS described by Piesman and Eisen identifies "key points of attack" for tick and TBD control (Figure 3) (Piesman & Eisen, 2008) . According to this framework, decisions on tick and TBD control are influenced at the national (national health organizations, national medical community), local (local medical communities, local homeowner groups) and individual (homeowners) levels through six major components: spatiotemporal epidemiological and spatiotemporal entomological risk models; exploitation of tick biology; accessibility of diagnostics, therapeutics, and vaccines; understanding of human risk behavior; and availability of tick control methodology. Each component has the potential to influence which strategic approaches to Lyme disease control and prevention are implemented at the national, local, and individual level.

Figure 3: Tick-borne disease decision support system (TBDDSS) framework



Source: Piesman and Eisan, Prevention of Tick-Borne Diseases, 2008

Although not specified in the local TBDDSS proposed by Piesman and Eisen, a wider range of public and private sector organizations other than local medical communities and homeowner groups are capable of making informed decisions about the implementation of Lyme disease control and prevention. An understanding of the variability of practices among high prevalent areas for Lyme disease and the factors that influence the inputs and outputs of a local TBDDSS. Clarifying this dynamic will assist in the formation of more effective implementation models for tick-control and Lyme disease prevention and encourage a wider range of public and private sector initiatives.

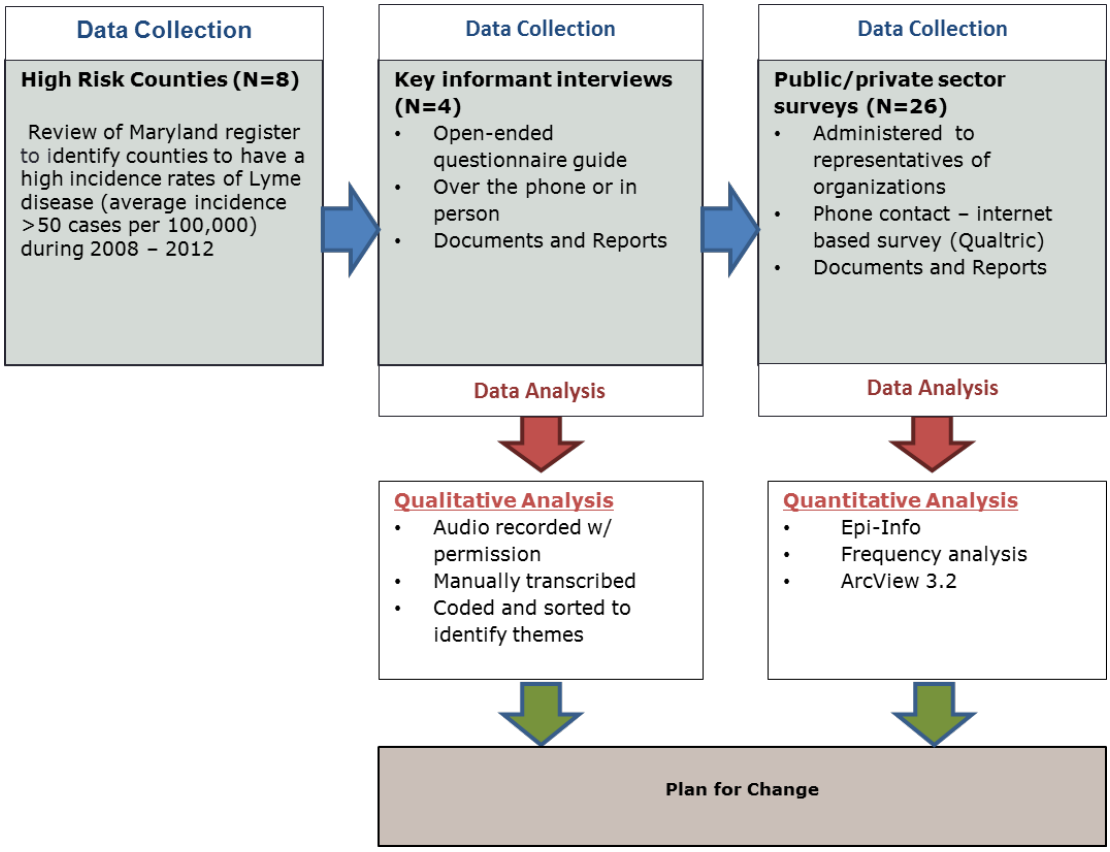
Study design

This study applied a retrospective, mixed-methods investigative approach to identify tick control and Lyme disease prevention activities implemented by public and private stakeholders in high Lyme disease prevalent counties of Maryland during 2009-2014. The study was not intended to establish causation between any one intervention, or combination of interventions, and disease outcome. The nuances between the public and private sector are often debated. For the purposes of this study, public sector stakeholders are entities that provide public services by and for the government and its citizens. Private sector organizations are run by private individuals or groups, and are not controlled by the state. In this sense a public non-profit organization may receive the majority of its funding from the general public, while a private non-profit organization receives most of its funds from only a few private sources, such as through donations from a single family or corporation. Medical providers, including primary health physicians, were not included as part of the study.

To identify public and private sector organizations involved in the implementation of tick control and Lyme disease prevention, key informants from the federal, state, and non-

profit sector were asked to provide their perceptions on tick control and Lyme disease prevention practices and to identify key public and private sector stakeholders. Based on the results of the key informant interviews, additional surveys were administered to appropriate representatives of public and private sector organizations that provide services within the eight selected counties and who may have a potential role in Lyme disease control and prevention activities. Information gathered from the interviews and surveys was used to describe the overall control and prevention strategies implemented in highly endemic counties, the frequency and coverage of these activities, estimated costs, and the overall motivation of participants to implement Lyme disease control and prevention strategies. Participants were asked to provide any documents for review that would provide details on specific tick-control or Lyme disease prevention activities occurring within their county (Figure 4).

Figure 4: Study concept



Study Population

Eight counties in Maryland that reported an average incidence greater than 50 confirmed cases of Lyme disease per 100,000 during 2008-2012 were selected for this study, including Kent, Caroline, Queen Anne's, Cecil, Talbot, Howard, Dorchester, and Washington. Incidence rates were based on the average annual number of confirmed Lyme disease cases reported per 100,000[8]. A confirmed case is defined by the DHMS as an individual presenting an EM with potential exposure in a Lyme disease endemic county less than 30 days before illness reporting. While this definition is not suitable for treatment or to capture actual prevalence in counties, it is appropriate as a surveillance definition to identify high-risk counties. Public and private stakeholders identified as providing services in the eight selected counties during key informant interviews were invited to participate in an online survey about tick control and Lyme disease prevention practices. Identified participants were encouraged to complete the survey even if they felt their organization was not contributing towards tick control or Lyme disease prevention.

The eight counties included in the study all reported reductions in incidence of Lyme disease from a 2008 to 2011, with the exception of Washington County which reported an increase in incidence from 36.9 in 2008 to 48.6 in 2011. Between 2011 and 2012 incidence rates increased in the majority of counties except Howard, Cecil, and Washington (Table 4). As previously discussed, changes in ecology, case reporting, surveillance, or control and prevention practices may affect a change in incidence but it remains uncertain to which degree. Regardless of the change in reported cases, the risk of *B. burgdorferi* transmission to humans in these 8 counties would be considered unchanged in the absence of any documented prevention or control strategy and without further entomological evidence to show a reduction in the level of circulating pathogen among *Ixodes spp*. and host species.

[8] CZVBD of Maryland provides public access to an online database of select notifiable diseases, including reported cases and incidence rates of Lyme disease by county from 2005 -2012, available at: http://ideha.dhmh.maryland.gov/SitePages/disease-conditions-count-rates.aspx

Table 4: Incidence of Lyme disease by year in counties reporting on average >50 cases per 100,000 between 2008 and 2012

County	2008	2009	2010	2011	2012	Average incidence 2008-2012
Kent	274.6	167.9	108.9	94.0	237.7	176.6
Queen Anne's	203.9	162.6	102.5	62.0	115.2	129.2
Howard	134.0	95.1	82.6	66.5	46.8	85.0
Cecil	103.5	138.9	111.8	90.5	84.6	105.9
Talbot	116.0	140.6	52.9	84.2	102.4	99.2
Caroline	86.8	98.9	51.4	27.3	119.2	76.7
Dorchester	62.3	18.7	42.9	42.9	92.2	51.8
Washington	36.9	59.6	67.2	48.6	44.2	51.3
Total (mean)	**127.3**	**110.3**	**77.5**	**64.5**	**105.3**	**97.0**

Source: http://phpa.dhmh.maryland.gov/SitePages/disease-conditions-count-rates.aspx

According to the 2014 County Health Rankings, there is no discernable difference between these eight counties compared the rest of the State. Howard is the largest populated county from the eight selected counties with the largest median household income of $108,234 per year and only 9.3% of the population living in rural areas (Table 5).

Table 5: Demographic distribution of targeted counties by race, language proficiency, rural status, and median income.

County	Demographics							Median household income ($)
	Pop.	African American	Asian	Hispanic	Non-Hispanic white	% Not Proficient in English	Rural	
Howard	299,430	17.4	15.1	6.0	58.4	3.2	9.3	108,234
Washington	149,180	9.9	1.5	3.6	82.6	1.1	29.5	52,604
Cecil	101,696	6.1	1.1	3.6	87.1	0.8	42.1	62,443
Queen Anne's	48,595	6.8	1.1	3.2	87.2	0.9	54.5	79,012
Talbot	38,098	12.8	1.3	5.7	78.8	1.0	54.7	61,529
Caroline	32,718	14.0	0.7	5.4	77.9	2.5	76.0	48,772
Dorchester	32,551	27.6	1.0	3.8	65.8	1.5	56.2	41,931
Kent	20,191	14.8	1.0	4.6	78.2	1.5	72.6	49,969

Source: 2014 County Health Ranking

Data Collection and Management

Key Informant Interviews

To identify public and private entities that have a role in Lyme disease control and prevention and to define the critical components emerging in the coordination and implementation of tick control and Lyme disease prevention practices in Maryland, semi-structured interviews were conducted between November and December 2013 with four experts on Lyme disease and TBDs that have participated in or supported Lyme disease control and prevention efforts in Maryland: one from the federal level (Centers for Disease Control and Prevention), two from the state level (Maryland Department of Agriculture and Maryland Department of Health), and one from the non-profit sector focused on Lyme disease advocacy. Informants were invited to participate in a confidential over-the-phone or in-person interview to identify current barriers and opportunities in the implementation of tick control and Lyme disease prevention practices.

Verbal consent was obtained from all four key informants to participate in the interviews. Two respondents declined permission to record and transcribe audio recordings. 'Audio memo' was used to collect digital recordings of interviews from consenting participants before being manually transcribed, coded and sorted in Excel; recordings were transferred to a secure computer within a day of being recorded. Non-recorded interviews (consent was not provide for recording) were also coded and sorted in Excel, but based on detailed field-notes from the primary investigator. All data from the key informant interviews and public/private sector surveys were transferred into Excel and stored on a non-networked, password protected computer. Shared documents pertaining to the control and prevention of Lyme disease within the county were downloaded for further review and used in the analysis to support key findings. All digital files were deleted within one month after transcription. All electronic datasets and hardcopy data collected from the online survey were de-identified. A copy of the questionnaire guide is provided in Appendix B.

Public/Private Sector Surveys

Based on the responses from key informant interviews, a list of potential public and private organizations involved in tick control and Lyme disease prevention in Maryland was developed; this included organizations representing accredited camps (day and overnight), commercial businesses (pest control, landscape and yard), county health departments, non-profits (advocacy and patient support groups), county parks and recreation, golf courses, hunting clubs, Boy Scout and Girl Scout troops, public schools, and universities. Military installations were not identified among the eight targeted counties and, therefore, were not included. Medical practitioners were also not included. To identify specific organizations and confirm their contact information (phone and/or e-mail) a Google search was conducted under each of the major organizational categories for the State of Maryland. The coverage area of an organization (addresses and/or zip codes of service coverage area) was verified through online sites. Only organizations with coverage areas inclusive of the 8 targeted

counties were included. An online survey was developed through Qualtrics[9] and made accessible to invited participants between March and August 2014. Survey results were processed through Qualtrics and downloaded as an Excel output. In total, 156 public and private organizations were identified from the 8 selected counties as potential stakeholders in supporting or participating in tick control and/or Lyme disease prevention activities. Each organization was initially contacted by phone at least once; the name of the primary investigator (PI), scope of study, and PI contact information was provided if an appropriate representative was not available. Organizations were encouraged to participate in the study even if they felt their organizations were not involved in tick control or Lyme disease prevention. Participants were informed that answers would be confidential and that they could decline to answer any question or terminate the survey at any point. A link to the online survey was provided to all participants via e-mail, followed by a second reminder 2-3 weeks later. Initial estimates assumed that 2-6 public/private sector organizations per county (N=18-36) would participate in the online survey.

Participants were asked to describe their involvement in tick control and Lyme disease activities, sources of information, costs associated with activities, spatiotemporal ranges of activities, frequency of application, and motivation for becoming involved. Participants were also asked to provide references or online links if available to any specified activities as reported by their organization. A copy of the survey guide is provided in Appendix C.

Data Analysis

A description of the local TBDDSS in Maryland was based on identified themes from the key informant interviews combined with the quantitative and qualitative results of the public/private sector surveys and document review. Broad themes were identified from the transcribed audio and field notes taken during the key informant interviews. Potential

[9] www.qualtrics.com

themes were identified through cutting and sorting quotes and expressions of the key informants into various groupings. Themes were then confirmed within and across each group through analysis of word and subject matter repetition, comparison of similarities and differences between key informants, and assessment of missing data; i.e., information that was not shared by informants.

Univariate analyses were conducted on each tick control and Lyme prevention practice to describe frequencies of practice, geographic coverage, temporal coverage, frequency of application, target population, and estimated costs. Frequency of activities was measured by the presence of each practice within selected counties during 2009-2014. Geographic coverage data was mapped using ArcView 3.2 to show geographic distribution of practices among selected counties. Temporal coverage of practices were calculated based on the number of days a specific activity remained effective, as determined by the frequency of application, and plotted by month and year.

Differences in perceptions of Lyme disease control and prevention practices by key informants and the actual practices implemented within counties served as another layer of analysis of the underutilization of preventative practices by the private/public sector. In the absence of certain practices hypotheses were developed to explain how certain variables present barriers to implementation within the current TBDDSS.

Limitations

This study was not intended to demonstrate causation between specific tick control and Lyme disease prevention practices and Lyme disease incidence rates in Maryland. Given the retrospective approach used to identify stakeholders and activities, and given the limited awareness of some individuals to their organization's activities and which activities constitute tick control and/or Lyme disease prevention, recall bias of participants may have underestimated or overestimated certain county practices implemented by the public and

private sector. However, even if only a percentage of actual practices were captured, these practices still represent what stakeholders believe are the most important (or memorable) practices in the control and prevention of Lyme disease.

Standardized data collection instruments and data coding was used to reduce the opportunity for biases during data collection and analysis. To reduce the possibility of researcher subjectivity or researcher-induced bias, data were gathered from multiple sources to validate information provided during key informant interviews, online public/private survey, and review of available documentation. Data from these three sources were compared - where data was contradictory, the investigator attempted to reconcile divergent information to the greatest extent possible and noted them in the result summaries.

CHAPTER 4: FINDINGS

Key Informant Interviews

Key informant interviews identified four major themes: 1) sources of information on Lyme disease control and prevention, 2) tick control and Lyme disease prevention practices, 3) coordination of tick control and Lyme disease prevention, and 4) key public/private stakeholders.

Sources of information on Lyme disease control and prevention

Key informants were asked to consider all sources of media involved in the dissemination of control and prevention practices for Lyme disease and other tick-borne infections, and which sources of information they preferred (Table 6). Results of peer-reviewed articles were identified by all four informants as preferred sources of information. Although the names of peer review journals were not specified by informants, the 22 articles identified in the literature review and published between 2004-2012 (February) appeared in 11 different journals; the majority of articles were published in Vector Borne Zoonotic Diseases (7), Journal of Medical Entomology (5), and Journal of Economic Entomology (2). None of these journals are open access. In general, CDC websites were mentioned favorably and the 2004 Tick Management Handbook produced by the Connecticut Agricultural Experiment Station was specifically referenced as a useful resource. One informant stated that the CDC website, including official reports, is "a valuable source of information for the everyday user" and often cross-referenced on state and non-profit websites. Informants expressed general concern about the accuracy of information provided on many websites. In the words of one informant, "you have to wade through a lot of stuff and the absolute worst answers can be painted up to be the very best thing."

Particular concern was expressed over the lack of objectivity of information posted on many non-profit websites and publicized through popular media outlets.

In addition to CDC websites, Maryland's Department of Health and Mental Hygiene (DHMH) and the University of Rhode Island (URI) were mentioned as reliable and comprehensive sources of information on Lyme disease and TBDs. Additionally, the Environmental Protection Agency's (EPA) website – Pestwise- was described by one informant as a "collaborative suite of EPA partnership programs that promotes environmental innovation in pest management." Also, mentioned were online materials and research links provided by the University of Maryland Extension (UMD - College of Agriculture and Natural Resources), the U.S. Department of Agriculture's (USDA) Forest Service and the Entomological Science Program at the US Army Public Health Command (USAPHC). The informant from the non-profit sector stated that the organization posts a wide range of information from various sources on its website and through social media sites like Facebook, however, these sites were not considered as reliable source of information by the other informants. A new consortium of organizations under the umbrella organization 'Partners Against Lyme and Tick Associated Diseases' was mentioned by one informant as a valuable resource to provide a new source of information on testing, diagnostics, and treatment for Lyme patients and support/advocacy groups (paltad.org - accessed 09/13/14).

Table 6: Preferred sources on Lyme disease control and prevention

Source	Information Type	Links
Peer Review Journals	Research	None specified
CDC	Lyme disease and TBD resource center	http://www.cdc.gov/lyme/ http://www.ct.gov/caes/lib/caes/documents/special_features/tickhandbook.pdf
DHMH	Lyme disease and TBD resource center	http://phpa.dhmh.maryland.gov/OIDEOR/CZVBD/SitePages/lyme-disease.aspx
URI	Lyme disease and TBD resource center	http://www.tickencounter.org/
EPA	Integrated Pest Management (IPM)	http://www.epa.gov/pestwise/ticks/[10]
USDA Forest Service	Wildlife and Vegetation management	http://www.fs.fed.us/research/
UMD	Tick biology, Pest Control, Pesticide use	http://extension.umd.edu/hgic/resource-library/links http://extension.umd.edu/learn/deer-and-wood-ticks
USAPHC	Entomology and Pest Management	http://phc.amedd.army.mil/organization/institute/dehe/Pages/EntomologicalSciencesProgram.aspx

Tick control and Lyme disease prevention strategies

Informants were hesitant to explain specific services that state or county departments should be responsible for implementing; suggesting that there is still a lack of evidence for most control and prevention activities in reducing Lyme disease and that most tick control and Lyme disease prevention strategies require a level of organizational coordination that is not in the purview of many health departments. As one informant explained,

[10] At the time of the interviews the June 2014 white paper, *Federal Initiative: Tick-Borne Disease Integrated Pest Management White Paper,* had not been released. Currently available at: http://www.epa.gov/pestwise/ticks/tick-ipm-whitepaper.pdf

> *Theoretically, counties and or states could take the role in spraying public places to control ticks in those areas; they could also take a role in putting out things such as 4 poster devices to control ticks on deer and hopefully reduce the tick population. Theoretically, there would be a role there but my concern is the efficacy of those interventions has not really been shown yet, and I don't think it would be appropriate for state and county health departments to spend their limited budgets on unproven impact on human health.*

This comment reflects frustration among state and county officials who feel pressure to respond to the increasing number of reported cases on the one hand, but on the other hand lack support from the federal or state level to apply more "aggressive" strategies because specific activities are waiting "to be validated in terms of their ability not to just control ticks, but to reduce human disease."

The concept of a package of services actively promoted and implemented by state and county departments for the control of Lyme disease raised divergent views on a standard approach. From the state perspective informants felt that there should not be a standard approach, as interventions depend on individual needs – needs of households, needs of communities, needs of counties, etc. They argued that intrinsically there are "cultural variations" between communities that would dictate which practices would be acceptable and, therefore, a standard approach is not possible. The federal perspective was more nuanced. While recognizing that interventions need to be tailored to the community, the informant from the federal level felt a series of tools could be implemented. The decision to use insecticides or to cull deer populations was specifically mentioned by all informants as examples of where divergent views emerge on standardized approaches:

> *There are some communities where you could really try and control the deer population and there are some communities where you could use lots of insecticide. Opinions about both of those topics are going to vary widely from community to community so I think that limits your ability to have a one size fits all approach.*

To this very point, the informant from the non-profit sector presented a case example from Loudon County, Virginia, where the County Lyme Disease Commission (set-up in 2012) was tasked with determining when and where to spray insecticides to control tick populations. The communities in the surrounding areas targeted for spraying rejected

the initial proposed plan due to concerns over the use of pesticides and so the committee had to go back and conduct additional studies on where to focus spray operations. This anecdote was provided not as a reason for why recommending standard practices is a challenge, but a positive example of a standard process for implementing tick control and Lyme prevention; i.e., an organizational structure for reviewing practices that maintains healthy dialog between stakeholders and creates opportunities for operational research to inform best practices.

The overall feasibility and effectiveness of a comprehensive tick control and Lyme disease prevention strategy was captured by the informant from the Federal level who stated, "If you could in a community get wide application of many different methods, including personal protective measures, including perhaps wide spread landscaping changes, including deer control and acaricide spraying. If you did all of those things, then it's hard for me to believe that you couldn't reduce the risk of disease. The problem is getting all of those things done - that's the challenge." Other informants echoed the sentiment that community-based activities can reduce transmission if only successful in increasing awareness of risk and adoption of personal protective measures. Despite reservations about being overly prescriptive and uncertain about the efficacy of particular strategies, informants mentioned the following activities as important contributors to the control and prevent Lyme disease:

Promotion of personal protective measures: Adopting personal protective measures was mentioned by all informants and is cited frequently in the literature as having some evidence of reducing human risk of Lyme disease. However, as pointed out by one informant, personal protective measures are individual acts – for personal protection to make a difference within a larger population, all individuals within an at-risk group need to be motivated to adopt effective personal protective measures. Educating others about personal protection is therefore an activity that potentially everyone and every group can

play a role in. As the federal informant explained "for personal protective measures then it really becomes about education and it becomes any group that wants to educate people. Everyone is a potential partner in education." One informant lamented that not enough information on Lyme disease and tick-borne infections are being provided at schools – "Why aren't school districts concerned?" Another informant raised concern that there was too much misinformation and that people consistently did not take the best advice or make the best decisions, stating: "They don't wash their clothes. They don't do an inspection when they get home. All of this starts as you as an individual; knowing what you need to do. People ought to do some self-education."

Informants said they would recommend personal protective guidelines as captured by their own preferred sources of information, but specifically mentioned using repellent, using permethrin treated clothing, showering after being tick habitat, and performing tick checks on both people and pets as important messages. The informant from the non-profit sector mentioned that in general language translations are still needed for prevention messages to more effectively reach at-risk populations and little effort was being made by groups to provide materials that target African American communities – "EMs don't always show-up as clearly on darker skin." Among the eight counties included in this study, Dorchester County had the largest African American population (27.6%) while Howard, Talbot, and Caroline had Hispanic populations greater than 5%. Howard and Caroline county had the largest percentage of population not proficient in English, 3.2% and 2.5% respectively (2014 County Health Survey). For tick-control and Lyme disease awareness to be effective, officials must seize on opportunities to develop educational materials targeting all significant demographic populations in their counties.

Environmental management (deer control, landscaping): Hunting groups were mentioned as having an important role in deer culling operations in Maryland. In theory, by working through hunting groups, deer populations can be reduced with the effect of

reducing Lyme disease risk. Informants seemed conflicted with recommending deer culling for Lyme disease prevention, yet still suggested that controlling deer populations was an important activity. As one informant explained,

> *Even though I don't know for sure what sort of level you would have to reduce deer to, in order to achieve something, it's clear that in many parts of the country deer populations are well outside the carrying capacity of the environment; and so I think there are other reasons to try and manage deer populations better…and whether or not that would really effectively control tick borne diseases I think is still an open question.*

The peer-review literature also suggests that while deer culling may reduce the density of ticks it may not be beneficial in reducing Lyme disease if deer populations aren't reduced and managed to an optimal level that is still undefined. The informant from the non-profit sector highlighted a December 2013 issue of National Woodlands Magazine (http://www.nwoa.net/) that specifically discusses prevention of TBD by managing white tail deer. One of the informants from the state level, however, felt that the real focus needed to be on controlling mice populations. Landscaping was strongly supported by the federal informant as a more sustainable activity to create spaces that are less hospitable to tick survival, although most likely more effective when deer populations are well managed.

Vector Control: Informants felt a wide range of groups potentially had a role in vector control, however it "presumes we know how to control ticks environmentally." Informants were divided on the use of acaricides with one informant from the state level stating that they were "against wholesale spraying because it knocks down everything else. I would not be spraying my yard." Other informants from the state and federal level suggested that some use of acaricides on host-targeted species like deer, or in targeted habitats, may have benefit. One informant mentioned in particular the role local government officials played in Gibson Island, Maryland, in adopting the 4-poster system and the reported success of the project in reducing entomological risk.

Monitor and inform populations of spatiotemporal risks: Two of the informants specifically raised the importance of supporting tick monitoring/ surveillance to understand the true risk of Lyme disease and density of tick species. One informant described efforts by Old Dominion University, Virginia, to organize periodic tick drags to monitor vector density and distribution. The Maryland Department of Agriculture conducts a free tick identification program[11]; however ticks are not tested for disease. Ticks are submitted voluntarily and the program is designed to only identify what kind of species it is and inform people who submit a tick specimen what kinds of diseases they could spread. Besides independent research studies, informants reported that there are no long-term tick monitoring programs in Maryland, only "passive surveillance of ticks when people voluntarily submit them - about a hundred ticks in a year." The informant from the non-profit sector mentioned their efforts to set up a nation lab that will test ticks for free. This raised an issue about best practices for saving removed ticks and whether people should save them pending the development of clinical symptoms of Lyme disease or other TBDs. Several private laboratories currently will charge to test ticks for diseases, and one informant highlighted the U.S. Army Public Health Command (UDSPHC) Tick Test Kit Program supported by the Department of Defense as an alternative to supporting tick identification and testing.

Research and Advocacy: All informants mentioned that additional federal funding is needed to support operational research and policy development for tick control and Lyme disease prevention. Having a well-articulated intervention, or action plan, was viewed as a critical role in creating research opportunities that drive policy changes. There was a general sense from informants that the state and county levels are still not pushing to do more - "[states] take their mandate from CDC and therefore are reluctant to take on

[11] Information on tick identification service - http://phpa.dhmh.maryland.gov/OIDEOR/CZVBD/SitePages/Tick%20Identification.aspx

additional responsibilities or initiative without CDC's input". The National Institutes of Health (NIH) and CDC initiated projects support much of the current Lyme disease research.

There was some disparate views on which partners are best suited for advocating on Lyme disease control and prevention practices. The informant from the non-profit sector felt that Lyme disease advocacy groups and universities have been influential in raising awareness and incorporating Lyme disease prevention messages into public health information, education, and communication strategies as well as playing a significant role in leading Lyme disease research and participation in control activities. However, the informant from the non-profit sector pointed out that not all stakeholders are open to collaboration and that successful implementing is dependent on individual decisions made on behalf of organizations. The efforts of Virginia's health commissioner, Karen Remly, to raise awareness among physicians about signs and symptoms of Lyme disease and reporting requirements was cited as a positive example of the important role this positon plays in advocacy and policy making.

Coordination of tick control and Lyme disease prevention

At the **state level** informants specified a distinction between coordination of activities and promotion of activities, with coordination involving the active facilitation of partnerships in the implementation of a broad range of tick control activities, and promotion involving the generation and dissemination of information on prevention and control activities. The comment by one state informant that they "purposefully stay ignorant of any of those things [coordination roles] because then people start asking for advice", suggests there is limited culpability states are willing to assume as coordinating agencies. Although most state health departments have a vector borne disease or infectious disease section that address vector control, most are not involved in TBDs. For instance, the State of Maryland may send out mosquito control units to go out and spray and implement control

measures for mosquitos, but that same coordinating role is not applied to TBDs. As explained by one informant, one of the reasons for the distinction between mosquito and tick borne diseases is historical. Mosquito control districts have been established for decades in many states to specifically control mosquitoes and mosquito-borne diseases. This was originally driven by concern over malaria and yellow fever, but more recently West Nile and Chikungunya. The other reason relates to differences in the vectors. The federal informant explained, "There at least are ways that you can sort of centralize some of your control [for mosquitoes] and you can do aerial spraying….. It's not clear how effect those techniques would be for ticks." One informant felt that state health departments should at least be responsible for "setting policy decisions", including sending out directives to physicians on reporting Lyme disease cases.

Informants agreed that coordination of TBD control and prevention activities are mostly handled at the **county level**; the county health departments typically address infectious and vector borne diseases, while environmental health departments address sanitation issues but also pesticide application. However, informants felt that the level of coordination demonstrated by county health departments varied considerably from state to state.

One of the state informants suggested that at the state and county levels tick surveillance should be more active, with environmental health departments coordinating regular tick drags in high-risk areas during peak seasons of disease transmission. In Maryland, the State Agricultural Department supports a tick identification program for passive surveillance; however, this program neither tests ticks for specific pathogens nor prospectively monitors high risk areas to determine when spatiotemporal thresholds would warrant a direct intervention.

Regardless of the level of coordination managed by state and county agencies, informants all agreed that government institutions should actively participate in basic services to control and prevent Lyme disease, including the promotion of health education, TBD surveillance, and participation in applied research. Informants also felt that states and counties have a role in developing and reviewing educational materials to ensure consistent and accurate messaging on what individuals within the general public can do to reduce their exposure to ticks and control ticks in their environment.

Key public and private stakeholders

Informants were asked to identify public and private partners that potentially play a role in supporting tick control and Lyme disease prevention practices at the county level. Informants acknowledged the potential for wider public and private sector involvement in the implementation of control and prevention practices, however, felt it would be difficult to assess the current level of engagement of specific groups. Informants were specifically probed on camps, churches, civic associations, clubs, commercial businesses (e.g. pest control businesses, landscapers, etc.), government agencies, independent researchers, non-profit organizations, park associations, and schools/ universities. Informants acknowledge these public/private sectors all had potential roles in tick control and Lyme disease prevention in addition to city councils, county supervisory boards, advocacy groups, military bases, neighborhood associations, golf courses, scouts, and hunting groups. Informants felt that these private and public sector organizations could all have an impact on Lyme disease control and prevention by educating their constituents on personal preventative behavior, raising awareness about risks, participating in IPM activities, and supporting advocacy efforts. Private stakeholders like commercial pest control companies and landscapers were expected to play a consistent role in helping to reduce overall tick density. Universities, in particular, were mentioned as playing a key role in advancing research on Lyme disease control and prevention practices.

Public Private Sector Survey

Based on the public and private partners identified during the key informant interviews, a list of 156 public and private organizations was generated that potentially play a role in tick control or Lyme disease prevention in the eight selected counties. For this study, 120 heads of organizations were successfully contacted by phone and invited to participate in an online survey; from these 120 representative, 108 were sent an e-mail with a link to the online survey and sent an e-mail reminder 2-3 weeks later. A total of 29 participants opened the online survey and 26 of these participants initiated a response, including county health departments (n=6), non-profit organizations (n=5), schools and universities (n=5), parks and recreation (county parks and golf courses) (n=4), camps (n=3), commercial pest control businesses (n=1), hunting clubs (n=1), and boy scout troops (n=1).

Which public and private organizations implemented tick-control and Lyme disease prevention practices?

Among the 26 survey participants, a total of 18 respondents indicated that their organizations participated in a tick-control or Lyme disease prevention activity over the last five years, or planned to participate over the next 12 months. Within the catchment area of the eight selected counties, these respondents represented county health departments (n=6), non-profit organizations (n=5), schools/universities (n=2), county parks (n=2), commercial pest control (n=1), hunting clubs (n=1), and Boy Scouts (n=1). Non-profit organizations were comprised of Lyme disease advocacy and patient support groups; schools/universities included a school district and an area university.

Participants who reported that their organizations were not actively involved in Lyme disease control and prevention activities in Maryland included school districts (n=3), camps (n=3), and parks (n=2). Despite reporting no involvement, two of these respondents still indicated some level of participation in health education and promoting personal protection

including doing daily tick checks among their constituents, encouraging constituents to wear long pants and shirts and using bug spray when hiking outdoors; the same organizations were uncertain of whether anything else could be done to prevent/control Lyme disease. One of the county park representatives that indicated that their park was not involved in Lyme disease control and prevention suggested that current control and prevention activities are handled through the health department. Two of the organizations not participating in control and prevention activities recommended that risk maps be provided to organizations to geographically show where ticks are most abundant as well as to advocate for more public awareness in parks, school grounds, and other outdoor recreational areas. One of the non-participating school districts felt that the occasional TV spot, local newspaper, neighborhood association newsletter, etc. would be helpful, saying, "People need to know that they can get ticks in their own yards and landscapes."

Among the sources of information on Lyme disease control and prevention, representatives of the various organizations identified the sources of information that follow as a motivation for their organizations involvement in implementation. The majority of organizations (n=10) responded that their own personal experiences provided the greatest motivation for participation in activities (Table 7).

Table 7: Sources of information that encourage participation in Lyme disease control and prevention activities among public and private stakeholders

Source of Motivation	county health depts. (n=6)	non-profit (n=5)	schools and uni. (n=2)	county depts. of parks and rec. (n=2)	pest control (n=1)	hunting (n=1)	Boy Scouts (n=1)
Brochures	x		x	x			
Posters			x				
Television					x		
Radio					x		

Source of Motivation	county health depts. (n=6)	non-profit (n=5)	schools and uni. (n=2)	county depts. of parks and rec. (n=2)	pest control (n=1)	hunting (n=1)	Boy Scouts (n=1)
Research Publications			x				
Doctors						x	
Business Opportunity					x		
Personal experience	x	x	X	x		x	x
Organizational Websites: www.marylandlyme.com; www.cdc.gov/lyme; www.Lymedisease.org; www.ilads.org; dhmh.maryland.gov; www.scouting.org; marylandpublicschools.org							

These experiences included having family members struggling with Lyme disease and co-infections, living in an area with a high density of ticks, physically seeing ticks daily, being previously bitten by a tick, constituents being made up of people who went many years without the proper diagnosis of TBDs, personally contracting Lyme disease and battling long-term effects, knowing a constituent or member of community that has contracted Lyme disease, and personally observing that there is more to do. Three of the stakeholders listed their organizational websites as sources of information for encouragement.

Survey participants also offered their suggestions on how to improve Lyme disease control and prevention activities. Recommendations captured a wide range of sentiments. Many addressed the need to improve communications and the quality of information on prevention provided to the general public, schools, and medical community:

- *More public awareness about the presence of ticks especially in parks, school grounds, and outdoor recreational areas.*

- *Provide information on symptoms of Lyme disease and areas of high risk on TV, local newspaper, neighborhood association newsletter, etc. People need to know where they can get ticks that transmit Lyme disease and when to seek medical help.*
- *Include information on Lyme disease and tick-borne infections in the state health education curriculum.*
- *Provide additional education and materials to the medical community on prevention, in addition to symptoms, reporting, and treatment protocols.*
- *Educate the public about co-infections. While Lyme disease might be most prevalent in certain areas there are other diseases being spread by ticks.*
- *Provide more resources and information on how communities can participate in tick control, deer reduction, and Lyme disease awareness.*

Most notable from participants were their expressions of frustration with the current approaches to preventing Lyme disease and tensions between various stakeholders:

- *The majority of county health department websites still have NO information on Lyme and tick borne diseases for the public. The ones that do often have inaccurate information and/or outdated links.*
- *Rarely do health department officials attempt to educate anyone on Lyme or TBDs, even when an opportunity presents itself and it involves no cost (e.g. not providing literature on TBDs at no cost to the health department at county fairs).*
- *Doctors need ACCURATE information on treatment, not typical CDC/IDSA garbage. Pediatricians are some of the most close-minded doctors where Lyme disease is concerned.*
- *Not enough is being done by our local health departments, school nurses, or local physicians on prevention of Lyme disease.*

Which control and prevention strategies were most often used and which were underutilized?

Among the available tick control and Lyme disease prevention strategies described in the literature and key informant interviews, the majority of respondents reported that their organizations had participated in the promotion of personal protective measures and limiting human exposure to spatiotemporal risks. Stakeholders also reported participation in included area-wide application of acaricides (commercial), host-targeted application of acaricides, landscape and vegetation management, wildlife management, and biological approaches. Strategies not reported on were the use of prophylactic treatment, application of acaricides on domesticated animals, adding bordering to properties and fencing. Host vaccination and host treatment strategies were also not mentioned (Table 8).

Table 8: Lyme disease control and prevention practices implemented by public and private stakeholders in eight counties of Maryland from 2009-2015

Strategy	Activity	N	county health depts. (n=6)	county depts. park and rec. (n=2)	non-profit (n=5)	schools and uni. (n=2)	pest control (n=1)	hunt club (n=1)	boy scouts (n=1)
Limiting human exposure to spatiotemporal risks	Raise awareness and avoidance of high-risk habitats during peak transmission season	8	x	x	x	x			
	Conduct routine tick monitoring/identification (e.g. tick drags, tick counts from managed hunts)	4	x	x	x				
Promotion of Personal Protective Measures	Conduct regular tick checks to remove ticks properly < 24 hrs. after attachment	12	x	x	x	x			
	Wear appropriate/protective clothing (including permethrin impregnated/treated clothing)	10	x	x	x	x			x

Strategy	Activity	N	county health depts. (n=6)	county depts. park and rec. (n=2)	non-profit (n=5)	schools and uni. (n=2)	pest control (n=1)	hunt club (n=1)	boy scouts (n=1)
	Apply repellents (synthetic or natural based products) on skin	6	x	x	x				
Prophylactic treatment	Administer appropriate antibiotic soon after tick bite	0							
Area-wide or peripheral application of acaricides (commercial or public)	Type of acaricide not specified.	2					x	x	
Host-targeted application of acaricides	Application of acaricides to deer host species (e.g., 4-poster device)	3	x	x					
	Application of acaricides on rodent host species (e.g., bait boxes, permethrin-treated cotton balls	2	x	x					
	Application of acaricides on domesticated animals	0							
Landscape and vegetation management	Removal of leaf litter and brush	1			x				
	Bordering (e.g. cedar mulch,)	0							
Wildlife management	Host reduction/elimination (e.g. hunting, sterilization)	2		x	x				
	Fencing	0							
Biologic approaches	parasitic nematodes, parasitic wasp, Guinea Fowl, etc.	1			x				

Health education: One of the sections of the survey was specifically designed to capture efforts to promote personal protective measures and/or to raise awareness and avoidance of high-risk habitats during peak transmission season during educational outreach. The majority of stakeholders (n=12) identified with at least participating in educational outreach for Lyme disease prevention; this included representatives from the

non-profit sector, county health department, parks and recreation, and school district. These stakeholders specifically mentioned raising awareness of spatiotemporal risk at civic events, schools, churches, dining facilities, public fairs and festivals, libraries, and scouting events, as well as targeting individual home owners, park guests, scouts, and medical groups during various parts of the year. Among the key messages reported were:

- Be aware and avoid high-risk habitats during peak transmission season: *create safe zones where ticks are less likely to live and avoid high-risk habitats during peak transmission season; ticks are out whenever temperatures are regularly above 28 degrees; ticks are out in Maryland year-round.*
- Conduct regular tick checks: *conduct regular tick checks – after every outdoor activity; show how to properly remove a tick; remove ticks less than 24 hours; any time a tick is attached it has the potential for transmitting disease so regular tick checks are important (we cite studies which have proven that transmission occurs in less than 24 hour transmission).*
- Wear appropriate/protective clothing: *wear appropriate/protective clothing; tuck pants into socks or wear gaiters; wearing permethrin treated shoes and socks reduces a person's chance of getting a tick bite by over 70%.*
- Apply repellents on skin: *Apply repellents* (non-specific).
- Manage and treat morbidity (treatment): *support those who have Lyme disease; recognize Lyme disease symptoms; be aware of the types of co-infections that ticks carry.*

Stakeholders involved in educational outreach did not mention promotion of acaricides around residential properties, nor did they mention any messaging that would promote or encourage people to seek medical attention soon after a tick bite for prophylactic treatment with an antibiotic. The actually frequency that people should apply personal protective measures or conduct routine monitoring of ticks was not specifically reported on.

Survey participants reported that key messages were disseminated and shared with targeted audiences through emails, websites, support group meetings, special programs, newspapers, TV, radio, during Lyme disease awareness month (May) activities, local talks, posters, e-mails, blog posts, word-of-mouth, bulletin boards, flyers, fact sheets, Facebook, Twitter, media releases, diagrams, books, interviews, brochures, and school curriculum[12].

Limiting human exposure to spatiotemporal risks: The concept of limiting human exposure to areas with a high density of ticks, in particular *Ixodes scapularis* and *Ixodes pacificus,* was captured both in the educational messages promoted by participants, but also in the participation in routine tick monitoring/identification (e.g., tick drags, tick counts from managed hunts). Routine tick monitoring and tick identification was reported in all of the 8 selected counties by representatives from the county health department, non-profit organization, or parks and recreation. This includes conducting tick drags or collecting ticks from deer during managed hunts to monitor tick densities during 2009-2014 during various months of the year. One participant reported that ticks are reportedly tested for disease when funding is available or may be sent to the University of Massachusetts 'Submit a Tick' program[13]. If ticks are found on children at events, one participant reported that their organization would assist the child in keeping the tick(s) in a baggie so the child's doctor could recommend testing it, if necessary.

Area-wide or peripheral application of acaricides (commercial or public): Use of an area-wide acaricide was specifically mentioned in reference to commercial application; i.e., private for-hire spraying by a pest control company. One private pest control company and a hunting club reported participation in commercial spray operations of targeted

[12] School health education curriculum at the elementary, middle and high school level includes a unit on disease prevention. Teachers decide on content depending on needs of their school community

[13] The Laboratory of Medical Zoology at the University of Massachusetts-Amherst tests ticks to determine whether or not they carry the pathogens that cause Lyme Disease and ten other tick-borne pathogens. The fee for individual tests is $50 per disease test. http://ag.umass.edu/services/tick-borne-disease-diagnostics

residential lawns in Howard County at various and unknown frequencies between 2009 and 2014. The stakeholders did not report on the type of acaricide used. It is possible that a combination of synthetic pyrethroids, entomopathogenic fungal, natural organic compounds, and descants/soaps were used during this period, however, this was not specified in the survey.

Host-targeted application of acaricides: The Health Department and Parks and Recreation in Howard County reported application of an acaricide on rodent host species using permethrin-treated cotton balls - "tubes with insecticide" - in open fields. A Tick Tube is a commercially available product aimed at the natural nesting instincts of mice. Mice take the permethrin-treated nesting material from the tube back to their nest. The permethrin on the cotton kill larval and nymphal ticks bloodfeeding on mice, which are the main source of infection to ticks. Tick Tubes should be applied in July/August (when larvae are actively feeding) and again in April/May, in areas where mice will find them (Mather). Howard County reported the use of Tick Tubes from 2012-2013 applied 2x per year (April and September). In addition, application of acaricides to deer host species using the 4-Poster device was reported as part of a partnership between the county health department and parks and recreation in Howard County and may have been ongoing since 2009. There was no mention of using acaricides on dogs, or other domesticated animals, as part of a host-target strategy to control tick populations.

Landscape and vegetation management: Landscape and vegetation management as an activity was reported by a non-profit stakeholder responsible for the Howard County Conservancy Nature Centers in Woodstock and Elkridge, MD. For this activity the stakeholder described keeping trails wide so that "visitors do not have to brush up against long grasses while hiking." Conducting controlled burns was not mentioned. Bordering was also not specifically mentioned although operationally it is more applicable to individual homeowners.

Wildlife management: Host reduction, in particular, of deer populations, was reported by representatives from non-profit organization and parks and recreation in Howard County. The hunting club that responded to the survey did not indicate this as an activity. The non-profit organization specifically reported that over the last 5 years a Fraternal Order of Police hunting group has been invited during deer season to cull herd in Howard County between twice a week to twice a month during October and March. Participants did not mention the strategic use of fencing to manage wildlife in and around residential areas or other high risk areas.

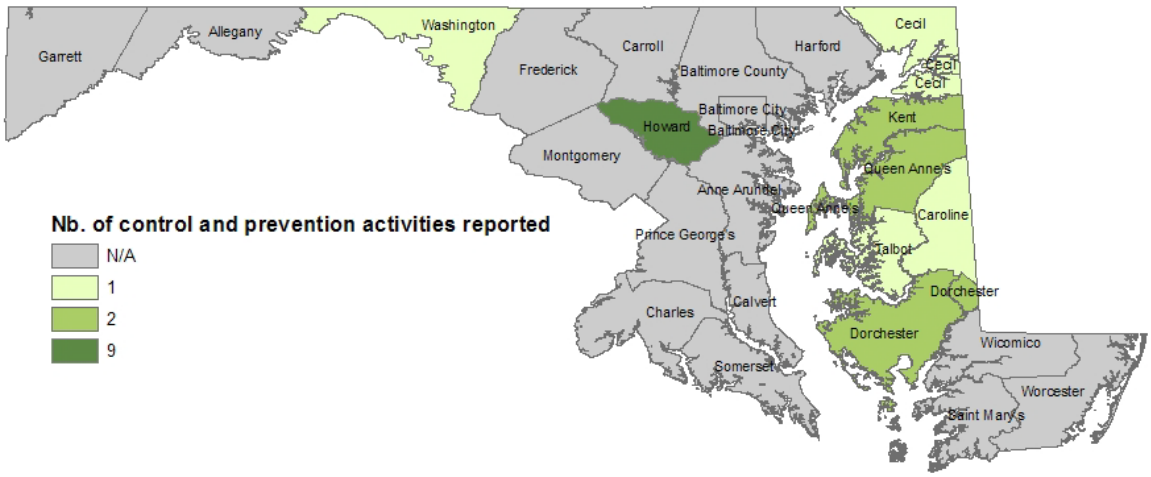
Biologic approaches: Several biologic approaches have been described in the literature including the use of parasitic nematodes, parasitic wasp, and Guinea Fowl. One of the non-profit stakeholders specifically described the "promotion of snake habitats" as a strategy to control mice and tick populations. By making sure that there are decomposing logs and stumps near agricultural border areas where mice often live, the organization was providing better breeding ground for the snakes (specifically black rat snakes) that keep mouse populations in check. The stakeholder claimed that "educating adults about [snake promotion] is particularly effective, as they often dislike snakes and want to see them removed from neighborhoods, local park areas, and wilderness areas. The snakes' role in Lyme prevention makes the adults more okay with them." This strategy was specifically described and used at the Howard County Conservancy Nature Center in Woodstock, Maryland from 2009 to 2014.

What were the geographic and temporal coverage of tick-control and Lyme disease prevention practices by county?

The geographic coverage of Lyme disease control and prevention activities was mapped using ArcView 3.2 to show geographic distribution of activities implemented between 2009-2014, as reported by participants among the eight selected counties (Figure 5). Howard County reported the greatest range of activities (n=9), including educational

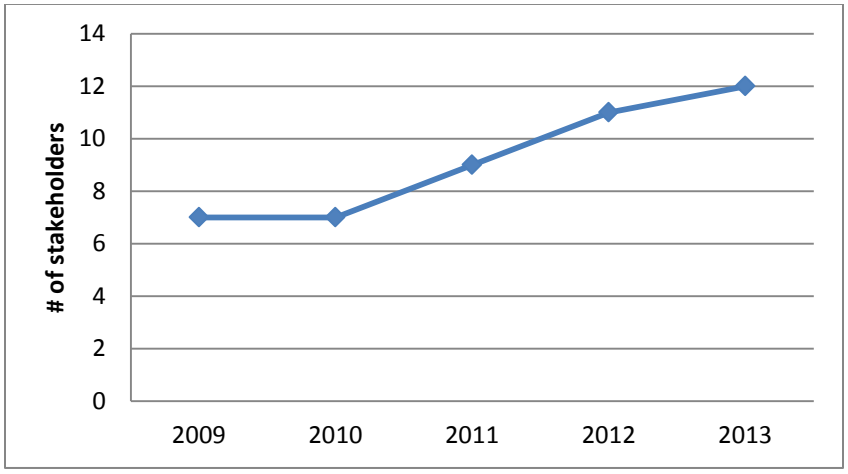
outreach that supported (1) awareness and avoidance of high-risk habitats during peak transmission season, (2) regular tick checks (remove ticks properly less than 24 hours after attachment), and (3) wearing appropriate/protective clothing. Additionally, Howard county supported (4) routine tick monitoring, (5) use of area-wide acaricides, (6) application of acaricides on rodent host species, (7) application of acaricides on deer host species, (8) removal of leaf litter and brush, and (9) biologic approaches (promotion of snake habitats). The integration of tick control/disease agent reduction and Lyme disease prevention activities was only observed in Howard County. Other counties only reported on activities that were primarily aimed at modifying human behavior to reduce exposure to ticks, not to reduce tick populations or reduce the level of circulating infection in host species as an overall objective.

Figure 5: Distribution of Lyme disease control and prevention activities supported by public and private stakeholders in 8 counties of Maryland, 2009-2014



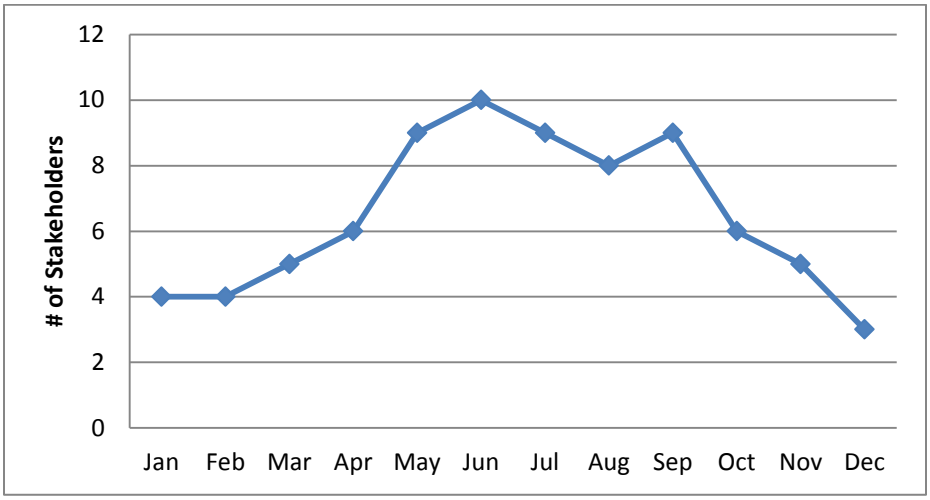
Promoting Lyme disease prevention though education was the primary intervention described by participants (n=12). Based on the temporal activity of organizations over the last five years, Figure 6 shows that the number of districts providing information on Lyme disease prevention increasing each year between 2009 and 2013.

Figure 6: Number of public and private stakeholders providing educational outreach on Lyme disease prevention, 2009-2013



While certain stakeholders were active in promoting prevention messages (limit human exposure to spatiotemporal risks and practice personal protective measures) throughout the year, the majority of stakeholders reported active involvement in education between the months of April and October, which coincides with the period of greatest tick activity. Stakeholders reported that educational outreached was mostly irregular.

Figure 7: Number of public and private stakeholders providing educational outreach for Lyme disease prevention by month



Tick Control/Disease Agent Reduction activities were reported only in Howard County from 2009 to 2013, with most stakeholder involvement between March and October, with the exception of deer culling which occurred between October and March.

Which groups or venues were the targeted for tick-control and Lyme disease prevention?

While some participants only mentioned students as a target group for promoting personal protection measures, stakeholders described a number of different venues at the county level through which messages were disseminated and activities implemented. These venues provide some measure of diffusion and how activities are being targeted within counties (Table 9).

Table 9: Targeted venues for dissemination of messaging and implementation of activities

Strategy	Venue				
	Parks / public spaces	Individual Households /residents	Community events/meeting places (schools, churches, dining facilities, county fairs, Library)	Medical Establishments / Individual physicians	Commercial spray operators
Health Education	X	X	X	X	X
Application of area-wide insecticides	X	X			
landscape management / fencing	X				
treatment of rodent host species with insecticides	X				
treatment of deer host species with insecticides	X				
reduction of deer populations	X				

Strategy	Venue				
	Parks / public spaces	Individual Households /residents	Community events/meeting places (schools, churches, dining facilities, county fairs, Library)	Medical Establishments / Individual physicians	Commercial spray operators
tick monitoring	X				
Biological	X				

What were the estimated costs of tick-control and Lyme disease prevention practices?

Stakeholders were asked to report on the estimated costs for the various control and prevention practices that they participated in. Table 10 summarizes the costs by activity and cost category. Great variability was reported by stakeholders on the estimated cost range of each activity. In general, most stakeholders reported that health education was less than $100 per year (range $100-$1,499), while the median cost category of tick control activities as $500-$999 per year, with one stakeholder reporting that deer reduction costs averaged $26,000 per year. As part of a larger IPM strategy, the scope and cost structure of various combinations of activities will need to be measured and validated. Future studies, for example, should consider the demand from residential and commercial customers for pest-free environments and the associated payments for such services as a measure of future public and private sector investment in tick control. Further analysis of tick control and Lyme disease prevention will also benefit from discerning costs for interventions in comparison to impact on Disability-Adjusted Life Year (DALY) One DALY can be thought of as one lost year of "healthy" life. The sum of these DALYs across the population, or the burden of disease, can be thought of as a measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability. DALYs for a disease or health condition are calculated as the sum of the Years of Life Lost (YLL) due to premature mortality in the

population and the Years Lost due to Disability (YLD) for people living with the health condition or its consequences.

Table 10: Estimated costs for Lyme disease control and prevention by activity

Activity	Cost Category ($)	F
health education	< $100	6
	$100-$499	2
	$500-$999	1
	1,000-$1,499	1
	$1,500-$2,000	
	Other-staff time	2
landscape management / fencing	< $100	
	$100-$499	1
	$500-$999	
	1,000-$1,499	
	$1,500-$2,000	
	Other	
area-wide or peripheral application of acaricides (commercial application)	< $100	
	$100-$499	
	$500-$999	2
	1,000-$1,499	
	$1,500-$2,000	
	Other	
treatment of rodent host species with insecticides	< $100	
	$100-$499	
	$500-$999	2
	1,000-$1,499	
	$1,500-$2,000	
	Other	
treatment of deer host species with insecticides	< $100	
	$100-$499	
	$500-$999	
	1,000-$1,499	
	$1,500-$2,000	1
	Other-staff time	2
reduction of deer populations	<$100	1
	$100-$499	
	$500-$999	
	1,000-$1,499	
	$1,500-$2,000	
	other ($26,000 per year)	1
tick monitoring	<$100	1
	$100-$499	1
	$500-$999	1
	1,000-$1,499	

Activity	Cost Category ($)	F
	$1,500-$2,000	1
	Other	
biological control - promotion of snake habitat	<$100	1
	$100-$499	
	$500-$999	
	1,000-$1,499	
	$1,500-$2,000	
	Other	

CHAPTER 5: DISCUSION AND CONCLUSIONS

How did the public and private sector influence the frequency and coverage of Lyme disease control and prevention practices in Maryland during 2009-2014?

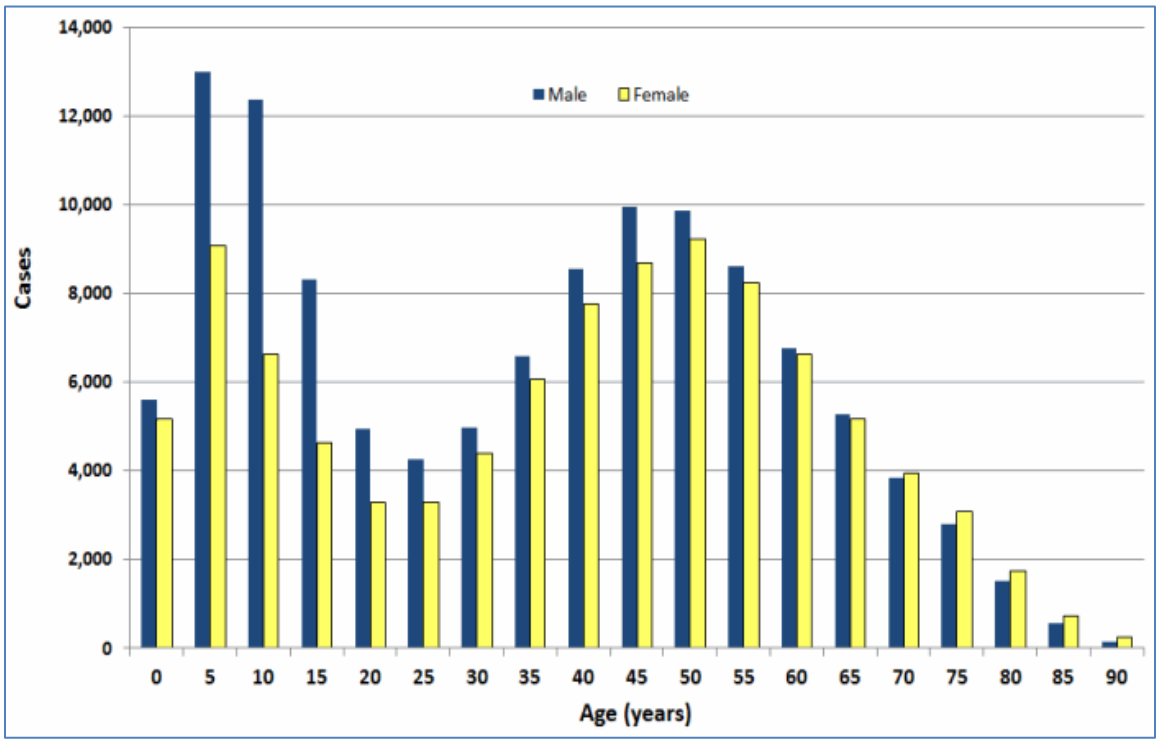
A common perception expressed in the peer review literature and reflected in the TBDDSS is, "when dealing with tick-borne diseases, such decisions are made at the family or individual level. Mosquito control is a community responsibility; tick control is an individual homeowner responsibility" (Joseph Piesman, 2008). The results of this study challenge that assertion. This study provides evidence that TBD control and prevention should be framed not just as a family or individual activity. Mounting evidence suggests a local TBDDSS supports much more than medical communities and homeowner groups, but a larger public and private sector effort involving a much broader range of stakeholders.

The role of the public and private sector

In Lyme disease prevalent counties of Maryland (greater than 50 cases per 100,000, 2008-2012) a diverse number of tick control and Lyme disease prevention activities were supported by the public and private sector between 2009-2014, including stakeholders from the county health departments, departments of parks and recreation, Lyme disease advocacy and patient support groups, school districts, universities, commercial pest control, and civic organizations (hunting clubs and the Boy Scouts of America). Several camps, school districts, and county departments of parks and recreation indicated that their organizations did not participate in Lyme disease control and prevention. The lack of any defined activity among these stakeholders indicates that among high prevalent counties there is still a lack of awareness about the role of public and private stakeholders in the

control and prevention of TBDs. The possible disenfranchisement of these particular stakeholders from Lyme disease control and prevention activities is of special concern considering that school-age children are more likely to be exposed to ticks at camps and other outdoor recreational settings. Figure 8 shows the average number of confirmed Lyme disease cases reported in the United States by age and sex. The graph clearly shows two peaks – one in children ages 5-15 years of age (especially males) and the other in adults ages 40-55 years of age.

Figure 8: Confirmed Lyme disease cases by age and sex--United States, 2001-2010



Source: *http://phpa.dhmh.maryland.gov/SitePages/disease-conditions-count-rates.aspx*

According to the TBDDSS framework, six major components influence decisions on tick and TBD control, including results of spatiotemporal epidemiological and spatiotemporal entomological risk models; exploitation of tick biology; accessibility of diagnostics, therapeutics, and vaccines; understanding of human risk behavior; and availability of tick

control methodology. The process through which data and information from these various components are effectively gathered and coordinated for decision-making at the local level needs further investigation. This study suggests nuanced differences in the roles of stakeholders related to which activities they are willingly to support and how information is accessed, used, generated, and disseminated. Based on the reported activities in the study, how stakeholders use information defines their function in the coordination, implementation, promotion, and generation of tick control and Lyme disease prevention strategies.

Coordination at the county level requires knowledge and understanding of the networks that link federal, state, and local levels together. This function demands organizational and leadership capacity to dictate control and prevention strategies across a wide range of stakeholders, and be provided the mandate as such to involve other public and private stakeholders, including the medical community. Coordination functionality was most clearly shown by county health departments and departments of parks and recreation in their partnership in the use of host-targeted application of acaricides. Implementation by stakeholders involves using information to build the necessary human and financial resources to apply tick control and Lyme prevention practices, although not necessarily in a coordinated manner. This functionality requires some degree of technical skills and ability to process data into actionable and measurable intervention. Promotion, on the other hand, is a function of disseminating information to inform a large audience about tick and deep control practice. Stakeholders who actively create new sources of information, such as research sponsored by the local university that produces disease risk maps or provides a better understanding of transmission dynamics is adding to the knowledge base; these stakeholders are participating in information generation. Differences in function becomes important when understanding the larger local TBDDSS and how various stakeholders interact and implement activities.

Tick control and Lyme disease prevention activities

A number of control and prevention strategies described in Table 2 were not mentioned by participants. The exclusion of these activities may reflect natural limitations of what the public/private sector can feasibly support as well as activities that are more suitable for homeowners or pet owners. Activities such as immunizing pets or applying an acaricide on domesticated animals are clearly limited to pet owners (primarily dog owners) and perhaps too exclusive for public and private sector initiatives. As part of landscape/vegetation and wildlife management strategies, creating tick-safe borders along properties and installing fencing to prevent deer migration were not specifically mentioned but may again be viewed as more of the responsibility of individual homeowners. It could be argued there could be application to larger public spaces including parks and school grounds. Lowering the prevalence of *B. burgdorferi* infection in reservoir hosts and/or host-seeking ticks, including the use of Oral OspA vaccine and Oral bait formulated with doxycycline for rodents, are still considered experimental despite some limited field studies and currently not commercially available to the public. It is not surprising, therefore, these activities were not listed. While area-wide or peripheral application of acaricides was reported as a commercial venture, targeting residential homes as part of a pay-for-service, the various categories of acaricides (synthetic pyrethroids, entomopathogenic fungal agents, natural organic compounds, soaps and desiccants) were not specified, which leaves some uncertainty about the acceptability of this strategy if were to be part of a larger coordinated public health effort. Finally, none of the stakeholders referenced IDSA's recommendation to administer appropriate antibiotic soon after tick bite. Absence of this strategy may likely reflect operational division between the medical and public health communities on who is responsible for advising the public on prophylactic treatments. In addition, concerns have been raised that the recommendation is poorly supported by literature (Schwartz, 2012) and difficult to implement in clinical settings if practitioners are unaware of the species of tick or the local rate of infection of ticks with *B. burgdorferi*. Moreover, some have

speculated that a dose of doxycycline could potentially mask symptoms without actually clearing the infection, leading to additional health complications and drug resistance.

Even though a small percentage of the potential public and private sector stakeholders participated in the study, the variety of activities captured suggest that IPM components are being supported and sustained by the local TBDDSS in Maryland, most notably in Howard County where both Lyme disease prevention strategies and tick control strategies were reported by stakeholders. According to data available from the CZVBD, in 2008, Howard County was more likely to report a case of Lyme disease then Kent, Caroline, Queen Anne's, Cecil, Talbot, Dorchester, and Washington Counties combined (OR =1.30, 95% CI:1.13–1.50; p< 0.002). By 2013, residents of Howard County were less likely to report a case of Lyme disease compared to the same counties after at least five years of both Lyme disease prevention **and** tick control activities (OR =0.45, 95% CI:0.36–0.57; p< 0.002). Between 2008 and 2013, the number of Lyme disease cases reported from Howard County decreased from 369 to 92 cases, a reduction of 75.1%. During the same period, the combined number of Lyme disease cases reported in Kent, Caroline, Queen Anne's, Cecil, Talbot, Dorchester, and Washington Counties decreased from 400 to 289 cases, a reduction of only 27.8%. Public and private stakeholders in these counties only reported participation in Lyme disease prevention **and not** tick control activities.

Although Lyme disease prevention messaging was supported by stakeholders in all selected counties, the combined role of tick control in Howard County may have had an additive effect on reducing transmission in high risk areas. The fact that Howard County is twice as large as the next largest county in the study (pop. 299,430), is primarily urban (90.7%), and has a median household income level almost $30,000 - $60,000 more than the other counties is likely a contributing factor to the county's ability to support tick control activities (County Health Rankings, 2014). Cost estimates determined by stakeholders

suggests that most tick control strategies cost more per year than basic educational outreach focused on personal protective measures and avoidance of high-risk habitats.

Replication of activities from one county to another may not be easily achieved or even be necessary depending on the six major components of the TBDDSS that support decision-making at the county level (spatiotemporal epidemiological and spatiotemporal entomological risk models; exploitation of tick biology; accessibility of diagnostics, therapeutics, and vaccines; understanding of human risk behavior; and availability of tick control methodology). While managing information and data from these six components remains a challenge, it becomes the responsibility of federal, state, and county health officials to provide individuals and public/private stakeholders at a minimum with best-practices and recommendations on Lyme disease control and prevention. Findings suggest that the current TBDDSS model should more explicitly recognize and emphasize the responsibility and contributions of public and private sector stakeholders in the coordination, implementation, and promotion of tick and TBD control. Indeed, public and private sector organizations would benefit from future tick and TBD control models that better reflect their role in influencing the implementation of IPM strategies and disrupting disease transmission.

CHAPTER 6: PLAN FOR CHANGE

Although removed from subsequent reports, Healthy People 2010 set a target of reducing incidence in endemic states to 9.7 cases per 100,000 population (National Center for Health Statistics, 2012). This goal has never been met. Many persistent barriers that have prevented consensus on Lyme disease control and prevention can be attributed to an ongoing debate over the existence, prevalence, diagnostic criteria, and treatment of "chronic" Lyme disease (Tonks, 2007), or Post-treatment Lyme Disease Syndrome (PTLDS)[14]. PTLDS has been documented in a subset of individuals who experience persistent symptoms for six months or longer, even after antibiotic treatment. The exact etiology of PTLDS and burden on health care costs is unclear, although IDSA guidelines suggest that PTLDS is self-limited and of mild severity (Wormser, et al., 2006).

The rise of PTLDS is in some respects the result of a perfect storm; the absence of an acceptable vaccine, inaccurate diagnostic tests, an increase in co-infections caused by ticks, confusion surrounding case definitions, opposing views on therapeutic regimens, and spread of infection into previously undocumented areas. The impact of this storm continues to dominate headlines, chat room discussions, funding opportunities, and legislative action, with unintended consequences in hampering the development of a comprehensive tick control and tick-borne disease prevention strategy. Clear divisional lines have been set between certain medical and non-profit communities over PTLDS and treatment guides, with leaders on both sides biased towards their own treatment guideline; going as far as to be dismissive of Lyme disease prevention and control strategies coming from organizations that support an opposing view. The longer these divisions persist, the more challenging it

[14] For purposes of this paper PTLDS is interchangeable with chronic Lyme disease.

becomes for new information and innovation to be accepted and advanced that can potentially prevent TBD transmission.

Leadership Implications

Federal and State leaders must be thoughtful in how the public and private sector are engaged in future IPM initiatives and which tools will be used to facilitate the change process. The rate at which an IPM strategy spreads from the federal level to states and counties will depend on how leaders understand the processes by which new ideas are communicated among public and private stakeholders at the county level. Based on the previous TBDDSS model, it would behoove the federal level to embrace a more inclusive list of stakeholders and institute a participatory approach to future research among working group members. Diffusion theory suggests there are four main elements to consider in influencing the spread of IPM: the innovation itself, communication channels, time, and the social system in which the innovation is introduced. Looking at only one of these elements is not enough, and unfortunate much of the research to date has been focused on the innovation itself. For IPM to be widely adopted and become a self-sustained strategy, those is responsibility for TBD control and prevention need to understand the interaction of all four components.

Another important concept for leaders to understand are adaptive resource management (ARM) principles which recognizes that “decisions are never made with complete knowledge of local conditions, so monitoring is performed to gather data that will allow improved management efforts in subsequent interventions.” (Beard & Strickman, 2014). Adaptive Management is, and provides a structured process for decision making in environments where there is uncertainty, with the goal of reducing uncertainty over time through surveillance and monitoring. Opportunities to strengthen local surveillance programs for monitoring ticks, including species identification and tick infection rates, will be particularly important to this iterative process. The challenge for leaders using ARM will be

in finding a balance between generating evidence-based approaches that support the goals of IPM while trying to achieve the best short-term outcomes based on the current knowledge available to them (Allan & Stankey, 2009).

Emerging strategies for IPM

In June 2014, the Federal Initiative: Tick-Borne Disease Integrated Pest Management White Paper was released, representing the latest effort by the federal government to advance evidenced based policies on tick IPM programs. The white paper outlines a strategic plan for collaboration between seven federal agencies: Centers for Disease Control and Prevention (CDC), US Environmental Protection Agency (USEPA), US Department of Agriculture (USDA), National Institutes of Health (NIH), US Department of Defense (DOD), US Department of Interior (DOI-USGS), National Science Foundation (NSF). These agencies collectively form the TBD Integrated Pest Management Workgroup (TBD IPM WG), whose purpose is to:

- Collect, share, organize, and integrate information on best practices, including communications tools and resources, related to IPM of ticks and TBDs;
- Identify and prioritize research gaps and needs;
- Share agency-specific strategic plans relating to the control of ticks and the pathogens they may transmit;
- Develop white papers and a strategy for tick IPM and prevention of TBD and consensus documents that can be shared across US federal agencies for the purposes of improving and coordinating IPM programs and activities.

Among the initial recommendations of the working group is to set common goals, establish linkages between collaborative research directives, and continue community outreach education and collaboration. As part of community education and collaboration, the working group identified several additional communication outreach, education, and prevention goals, specifically to:

1. Provide evidence-based toolkits and other resources on prevention best practices to state and local public health partners;

2. Educate the public living in areas of risk on the efforts they can take to reduce risk of exposure to TBDs;
3. Develop and share information regarding landscape designs to reduce human/tick interaction;
4. Encourage efforts for targeted management of ticks in areas of highest TBD incidence;
5. Prepare joint and individual agency statements on TBDs to be incorporated into strategic and action plans.
6. Identify TBD experts in each federal agency for public outreach.

These goals represent real opportunities to improve IPM within counties most affected by TBDs and to provide much needed guidance and resources to states and counties, including recommendations on surveillance programs for tick monitoring and risk modeling, establishing a single repository of educational and outreach resources, and developing an operative model for effective tick control. Of remaining concern, however, is the degree to which the federal and state levels actively involve the public and private sector in shaping, approving, and adopting proposed activities and research opportunities. It remains unclear whether federally managed initiatives will trickle down to the public and private sector in high prevalent counties and be translated into effective and sustained disease control. To help ensure that the goals and objectives outlined by the TBD IPM WG result in sustained TBD control measures at the county level, the following recommendations are suggested:

Recommendation 1: Formation of county level Tick Borne Disease Committees (TBDC) as sponsors of IPM change initiatives.

Although public and private sector stakeholders have easy access to a litany of information from internet sites on how to prevent and treat Lyme disease, and have invested in various components of an IPM strategy, a comprehensive organizational structure remains elusive for coordinating and implementing a long-term community-based IPM strategy in high risk counties. Without a strong coordinating body at the county level that is inclusive of key stakeholders, a state and regional approach to TBD control will be difficult to pursue. This study has shown that the public and private sector is capable of advancing an IPM strategy, but socio-economic differences between counties are likely

contributing to inequities between counties in the implementation of TBD control activities. A well supported TBDC, represented by the County Health Department and appointed board members among key stakeholders, is more apt to assist in the coordination and advocacy with the federal and state level to ensure adequate support is provided when and where needed and to facilitate research initiatives.

The Loudoun Lyme Disease Commission, Loudoun County, Virginia, is an example of how a TBDC could be structured (http://www.loudoun.gov/index.aspx?NID=2648), although each county may want to approach it differently. The process of setting-up a commission provides an opportunity to identify key stakeholders and adopt an ARM approach to enable participation in surveillance and monitoring to reduce uncertainty and make better informed decisions. This is a core component of IPM and an effective strategy to increase visibility of TBD activities and mediate conflict or disagreement.

Recommendation 2: Facilitation of stakeholder engagement and communication plan workshops.

A Stakeholder Mapping and Engagement tool developed by Katy Strei and Sally Colella (Strei & Colella, 2010) provides a potential mechanism to facilitate change and communicate federal goals on IPM while setting-up TBDCs. The workshop approach moves participants from "developing an awareness of the current network of stakeholders to actively developing a specific network that can help a change effort succeed." As part of stakeholder mapping it is therefore equally important to capture both stakeholders actively or passively supporting Lyme disease control and prevention as well as stakeholders that are less likely to support aspects of IPM, but are still influential in implementing disease control strategies including, environmental groups, mosquito control units, county boards, and commercial landscapers. Table 11 shows the potential degree of influence of known stakeholders on tick control; stakeholders are categorized as either having a high influence that can approve or block new IPM initiatives or a low degree of influence that cannot,

individually, approve or block it. Those with a high level of interest are typically more willing to invest time and effort into the overall goal, while stakeholders with a low level of interest remain uninvolved. The level of support of each stakeholder is captured by color: green indicates the stakeholder as actively or passively supporting the IPM goal; yellow indicates undecided or unknown; and red indicates actively or passively opposing the IPM goal.

Table 11: Stakeholder mapping (example)

Goal: Continue community outreach education and collaboration

Objective: Tick Control

High Influence	**Short and Tailored** • School Districts • Mosquito Control Units • County Board of Supervisors • Environmental Groups	**Stay Close** • County Health Department • County Parks and Recreation Department • Lyme Disease Advocacy Groups
Low Influence	**Be Aware** • Golf courses • Camps • Boy Scout Troops • Hunting Clubs	**Share Updates** • Commercial pest control • Universities • Commercial Landscaping
	Low Interest	**High Interest**

The type of engagement strategies recommended for stakeholders then depends on the goal and the placement of a particular stakeholder in the four-box matrix, where Short and Tailored strategies are for stakeholders that prefer to be passive about IPM but may emerge later in the process to block or slow down change. The recommend communication

strategy for these stakeholders is short and to the point; communicate only what is important, but do not ignore them. Stakeholders that should be engaged with a Stay Close strategy need frequent engagement and interaction to ensure the IPM strategy is aligned with expectations and understandings. A Be Aware strategy is applied to stakeholders that require minimal effort. Do not overinvest time in this group, but monitor their interests accordingly and provide information as necessary. The final stakeholder category are for those who are interested in IPM but do not require time soliciting feedback. These stakeholders should be approach, with a Share Updates strategy, where members are informed about the new IPM initiative and provided periodic updates (Strei & Colella, 2010).

While Table 11 is illustrative of how stakeholder mapping could assist with communication and outreach in high risk counties targeted for IPM, this process could be adapted for other settings as well. As part of the mapping exercise participants would be asked to create an Engagement and Communication Plan that encompasses the results of the mapping exercise and delves deeper into the communication vehicles preferred by different stakeholders and leadership styles.

Recommendation 3: Adoption of a behavior change communication (BCC) framework into personal protective measures for TBDs

As identified in this study, stakeholders use a wide variety of channels to disseminate messages and refer to a number of different sources for information. This has also been identified as an issue by the TBD IPM WG concerned that while the content of information might be reliable, "there is no single place where they are referenced. As a result, they are not as well accessed and utilized as they could be. Establishment of a well-organized, single domain for up-to-date and reliable information would be highly useful both for advertising their presence and for reducing efforts at developing tools that already exist." Many of the communication channels described by stakeholders fall into three broad categories of a BCC strategy: Mass media (radio, television, billboards, print material, internet); Interpersonal

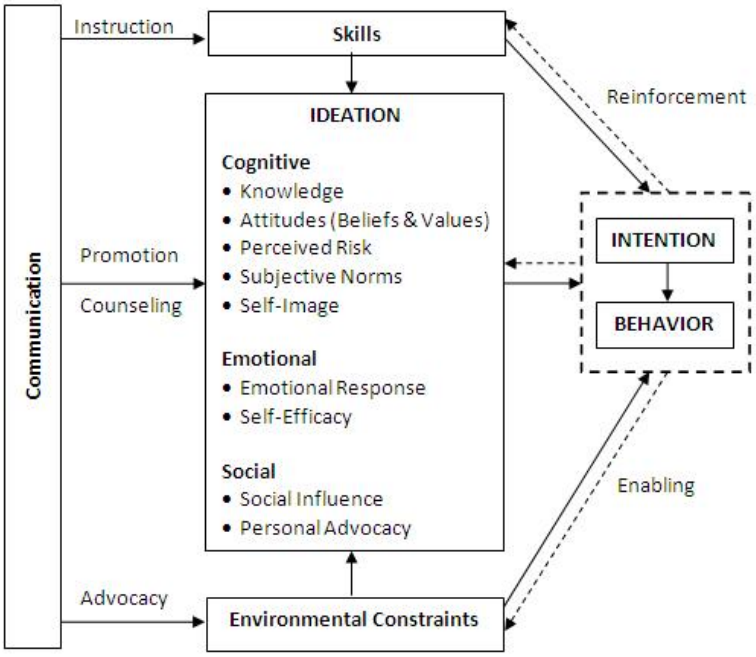
communication (client-provider interaction, group presentations); and Community mobilization. Yet rarely are distinctions made between these categories as part of a larger framework for promoting personal preventative measures, even though Lyme disease prevention is primarily concerned with an individual's decision to adopt protective behaviors before and after visiting high risk areas for transmission. Given that those behaviors are typically outside of what an individual might think is part of his/her normal routine, it is surprising that none of the sources of information mentioned by stakeholders discuss or even refer educators to the concept of BCC.

Figure 8 provides a BCC framework for explaining the communication approaches that contribute to reinforcing or enabling behavior. In this conceptual framework:

> *Communication designed to improve skills is identified as instruction, communication for removing environmental constraints is identified as advocacy, and communication designed to change ideational [cognitive, social, emotional] factors is identified as promotion. The model specifies how and why communication affects intention and behavior: indirectly through its effects on skills, ideation, and environmental constraints.* (MEASURE Evaluation PRH)

This framework is important for an IPM strategy because "promotion" is what drives most of the activities that are part of Lyme disease prevention. Promotion encourages individuals or populations to perceive given practices or behaviors. Promotional approaches should be designed to have a cognitive, emotional, and social effect, which in turn influences a person's intent to practice certain behaviors at critical times. Additionally, however, are instructional messages that need to build the skills of target groups to reinforce the intended actions and advocacy to remove environmental constraints that do not enable intention to turn in the desired change in behavior.

Figure 9: The Conceptual framework for BCC



Considering the strong emphasis on personal protective measures for prevention of TBDs there is very little evidence to show that educational materials are being effectively used to encourage positive behavior change. A case in point, the perceived risk of coming in contact with an infected tick is made stronger when stakeholders are directly involved with routine tick monitoring. One could simply argue that people living in high risk areas for Lyme disease just need to practice personal protective measures daily, but that might be an unrealistic expectation. Reinforcing and enabling individuals to determine when and where to adopt protective behaviors throughout the season is far more enabling than to be overwhelmed with a message of "anytime, anywhere." By introducing the basic concepts of a BCC strategy both researchers and stakeholders will have better tools to evaluate the impact of their actions and develop more effective messaging.

Recommendation 4: Development of a state organized IPM certification program for pest control operators and landscape companies.

The objective of creating an IPM certification program is to: 1) to promote and build understanding of IPM principals among commercial business and customers, 2) to leverage the skills and outreach of commercial pest control and landscape companies as part of a comprehensive IPM strategy, and 3) to provide a greater level of consumer confidence in 'tick-control' services offered by commercial businesses.

While several pest control and landscape companies in Maryland advertise tick control services, the study was unable to capture how these services are monitored within high risk counties or whether these services promote an IPM strategy. A state organized program would allow licensed pest control operators and landscape companies to be certified in basic IPM principles and practices. The certification would help verify a company's training in IPM and understanding of preferred practices. As captured in the study, public and private sector stakeholders are increasingly investing in tick control and Lyme prevention activities, including commercial pest control. Most recommended tick control activities involving landscape and vegetation management are targeted at homeowners as a more sustainable approach and a major component of IPM. Similar to improving adoption of personal protective measures, the conceptual framework for BCC also applies to promoting tick control through commercial businesses, specifically by improving the skills of commercial pest and landscape operators and raising consumer confidence that services are part of a larger comprehensive strategy to reduce human illness while managing resources responsibly and effectively to minimize the quantity of insecticides in the environment.

Immediate Action Steps

To encourage adoption of these recommendations, the following action steps will be taken by the PI, including:

1. Summarize and disseminate study findings through to research participants. In order to create consensus on the major barriers to implementation and to build support for recommendations, the major findings of the study will be summarized in a report and disseminated among study participants. This report will assist leaders at the federal, state, and county levels from moving away from framing tick control and Lyme disease prevention practices as a personal problem towards a more community-based approach that requires organizational and leadership changes in order to coordinate a comprehensive IPM strategy.

2. Presentations of findings to Lyme disease advocacy/support groups, county health boards, county parks and recreation. To support the interests of holding Stakeholders Engagement and Communication Plan workshops, the PI will be available to present study findings and recommendations to local stakeholders and facilitate the process of developing a network of stakeholders that can help implement IPM at a community level.

3. Develop and submit publication on BCC framework for promotion of personal protective measures and landscape management practices. To help strengthen communication strategies for Lyme disease control and prevention, the PI will adapt a BCC framework to more clearly define the major components that should be part of a communication strategy to encourage communities to adopt personal protective measures for the prevention of TBDs. By introducing the basic concepts of a BCC strategy in the peer-review literature on TBDs, both researchers and stakeholders will be able to develop more effective tools to evaluate the impact of personal

protective measures and landscape management practices and develop more effective messaging.

4. Develop proposal for state run IPM certification program for commercial pest control and landscape contractors. A state operated certification program on IPM will take time and resources to develop and implement, however there are several demonstrated models that could be adapted for the purposes of advancing IPM principles in the commercial sector, including state supported hunter safety courses offered online (currently not available in Maryland). The potential economic return on investment through a certification process and the benefits to more efficient use of pesticides and private resources will need to be closely monitored. The IP proposes to explore several different certification models and to propose a course design to the Maryland Department of Health and Mental Hygiene and Department of Agriculture, as well as for consideration of the TBD IPM WG.

Appendix A - Summary of Major Field-Based Tick-Control Activities conducted between 2004-2012 (Feb)

Objective*	Author	Title	Strategy: Activity	Indicator	Duration	Frequency of application
A	Stafford KC 3rd, Denicola AJ, Pound JM, Miller JA, George JE	Topical treatment of white-tailed deer with an acaricide for the control of Ixodes scapularis (Acari: Ixodidae) in a Connecticut Lyme borreliosis hyperendemic Community.	Host-targeted approaches: Treatment of deer host species with acaricides (4-poster device)	Reduced prevalence of host-seeking *I. scapularis* ticks	October to mid-December and March into May. September 1997 - May 2002	weekly
A	Daniels TJ, Falco RC, McHugh EE, Vellozzi J, Boccia T, Denicola AJ, Pound JM, Miller JA, George JE, Fish D.	Acaricidal treatment of white-tailed deer to control Ixodes scapularis (Acari: Ixodidae) in a New York Lyme disease-endemic community.	Host-targeted approaches: Treatment of deer host species with acaricides (4-poster device)	Reduced prevalence of host-seeking *I. scapularis* ticks	15 September to 15 December, 1997 to 2001; 15 March to 15 May, 1998 to 2002.	weekly
A	Schulze TL, Jordan RA, Hung RW, Schulze CJ.	Effectiveness of the 4-Poster passive topical treatment device in the control of Ixodes scapularis and Amblyomma americanum (Acari: Ixodidae) in New Jersey.	Host-targeted approaches: Treatment of deer host species with acaricides (4-poster device)	Reduced prevalence of host-seeking *I. scapularis* ticks	15 September to 15 December and 15 March to 15 May. 1997 to 2002.	weekly
A	Miller NJ, Thomas WA, Mather TN.	Evaluating a deer-targeted acaricide applicator for area-wide suppression of blacklegged ticks, Ixodes scapularis (Acari: Ixodidae), in Rhode Island.	Host-targeted approaches: Treatment of deer host species with acaricides (4-poster device)	Reduced prevalence of host-seeking *I. scapularis* ticks	15 September to 15 December and 15 March to 15 May. 1997 to 2002.	weekly
A	Carroll JF, Pound JM, Miller JA, Kramer M.	Sustained control of Gibson Island, Maryland, populations of Ixodes scapularis and Amblyomma americanum (Acari: Ixodidae) by	Host-targeted approaches: Treatment of deer host species with acaricides (4-poster device)	Reduced prevalence of host-seeking *I. scapularis* ticks	15 September to 15 December and 15 March to 15 May, 2003-2007.	weekly

		community-administered 4-Poster deer self-treatment bait stations.				
A	Carroll JF, Hill DE, Allen PC, Young KW, Miramontes E, Kramer M, Pound JM, Miller JA, George JE	The impact of 4-Poster deer self-treatment devices at three locations in Maryland.	Host-targeted approaches: Treatment of deer host species with acaricides (4-poster device)	Reduced prevalence of host-seeking I. scapularis ticks	15 September to 15 December and 15 March to 15 May. 1997 to 2002.	weekly
A	Dolan MC, Maupin GO, Schneider BS, Denatale C, Hamon N, Cole C, Zeidner NS, Stafford KC	Control of immature Ixodes scapularis (Acari: Ixodidae) on rodent reservoirs of Borrelia burgdorferi in a residential community of southeastern Connecticut.	Host-targeted approaches: Treatment of rodent host species with acaricides (bait boxes)	1) Reduced prevalence of host-seeking I. scapularis ticks 2) Reduced prevalence of *I.Scapularis* on targeted hosts 3) Reduced Infection rate of *I. scapularis* ticks infected with B. burgdorferi	1999-2001	monthly, or as needed
A	Hornbostel VL, Ostfeld RS, Benjamin MA.	Effectiveness of Metarhizium anisopliae (Deuteromycetes) against Ixodes scapularis (Acari: Ixodidae) engorging on Peromnyscus leucopus.	Host-targeted approaches: Treatment of rodent host species with acaricides (anisopliae-treated nesting material in artificial nestboxes)	Higher mortality rate of host-fed *I. scapularis* ticks	May 2002 - September 2002	biweekly
A	Dolan MC, Jordan RA, Schulze TL, Schulze CJ, Manning MC, Ruffolo D, Schmidt JP, Piesman J, Karchesy JJ.	Ability of two natural products, nootkatone and carvacrol, to suppress Ixodes scapularis and Amblyomma americanum (Acari: Ixodidae) in a Lyme disease endemic area of New Jersey.	Application of area-wide acaricides: natural organic compound (nootkatone and carvacrol)	Reduced prevalence of host-seeking *I. scapularis* ticks	May or June, 2006-2008	annual

A	Jordan RA, Dolan MC, Piesman J, Schulze TL.	Suppression of host-seeking Ixodes scapularis and Amblyomma americanum (Acari: Ixodidae) nymphs after dual applications of plant-derived acaricides in New Jersey.	Application of area-wide acaricides: natural organic compound (nootkatone and carvacrol)	Reduced prevalence of host-seeking *I. scapularis* ticks	2009-2010	annual
A	Stafford KC 3rd, Allan SA.	Field applications of entomopathogenic fungi Beauveria bassiana and Metarhizium anisopliae F52 (Hypocreales: Clavicipitaceae) for the control of Ixodes scapularis (Acari: Ixodidae).	1) Application of area-wide acaricides: entomopathogenic fungal agent (Beauveria bassiana Vuillemin, Metarhizium anisopliae Sorokin strain F52) 2) Landscape management: bordering	Reduced prevalence of host-seeking *I. scapularis* ticks	April or May, 1999-2000, 2002	annual
A	Garnett JM, Connally NP, Stafford KC 3rd, Cartter ML.	Evaluation of deer-targeted interventions on Lyme disease incidence in Connecticut.	1) Wildlife management: Reduction of white-tailed deer 2) Host-targeted approaches: Treatment of deer host species with acaricides	1) Reduction of white-tailed deer had no impact on incidence of EM rash 2) Host-targeted approach decreased incidence of EM rash	2002–2006	annual
A	Rand PW, Lubelczyk C, Holman MS, Lacombe EH, Smith RP Jr.	Abundance of Ixodes scapularis (Acari: Ixodidae) after the complete removal of deer from an isolated offshore island, endemic for Lyme disease.	Wildlife management: Elimination of white-tailed deer	1) Reduced prevalence of host-seeking *I. scapularis* ticks 2) Reduced Infection rate of *I. scapularis* ticks infected with B. burgdorferi	November 1996 - March 1999	annual
A	Jordan RA, Schulze TL, Jahn MB.	Effects of reduced deer density on the abundance of Ixodes scapularis (Acari: Ixodidae) and Lyme disease incidence in a northern New Jersey endemic area.	Wildlife management: Reduction of white-tailed deer	No impact on reducing prevalence of *I. scapularis* ticks	2002 - 2005	annual
A	Padgett KA, Casher LE, Stephens SL, Lane RS.	Effect of prescribed fire for tick control in California chaparral.	Vegetation management: controlled burns	No impact on reducing prevalence of *I. pacificus* ticks	June 1995	single event

A, C	Connally NP, Durante AJ, Yousey-Hindes KM, Meek JI, Nelson RS, Heimer R	Peridomestic Lyme disease prevention: results of a population-based case-control study	1) Wildlife Management: Fencing 2) Adopt Personal Protection Measures: Conduct regular tick checks 3) Application of area-wide acaricides: various 4) Landscape management: Bordering	Greater adoption of fencing for wildlife management in people without Lyme disease (reduced risk in developing Lyme disease)	2005-2007	varies
A,C	Vázquez M, Muehlenbein C, Cartter M, Hayes EB, Ertel S, Shapiro ED	Effectiveness of personal protective measures to prevent Lyme disease.	1) Adopt Personal Protection Measures: wear appropriate clothing 2) Adopt Personal Protection Measures: Apply repellents on clothes or skin	Greater adoption of Personal Protection behaviors in people without Lyme disease (reduced risk in developing Lyme disease)	Jul 2000 - Feb 2003	varies
B	Tsao JI, Wootton JT, Bunikis J, Luna MG, Fish D, Barbour AG.	An ecological approach to preventing human infection: vaccinating wild mouse reservoirs intervenes in the Lyme disease cycle.	Host Vaccination: OspA vaccine for rodents	Reduced infection rate of *I. scapularis* ticks infected with *B. burgdorferi*	1998-1999; 2001-2002	single event
B	Dolan MC, Schulze TL, Jordan RA, Dietrich G, Schulze CJ, Hojgaard A, Ullmann AJ, Sackal C, Zeidner NS, Piesman J.	Elimination of Borrelia burgdorferi and Anaplasma phagocytophilum in rodent reservoirs and Ixodes scapularis ticks using a doxycycline hyclate-laden bait.	Host treatment: oral bait formulated with doxyxycline for rodents	1) Reduced infection rate of *I. scapularis* ticks infected with *B. burgdorferi* 2) Reduced infection rate of targeted host with B. burgdorferi	May 2007 - Aug 2007	weekly
C	Daltroy LH, Phillips C, Lew R, Wright E, Shadick NA, Liang MH	A controlled trial of a novel primary prevention program for Lyme disease and other tick-borne illnesses.	1) Adopt personal protection measures: wear appropriate clothing, apply repellents, conduct regular tick checks. 2) Limit human exposure to spatiotemporal risks: Avoid high-risk habitats	Reduced prevalence of tick-borne illnesses	Jun-Aug, 1997 - 1999	daily
C	Vaughn MF, Meshnick SR	Pilot study assessing the effectiveness of long-lasting permethrin-impregnated clothing	Adopt Personal Protection Measures: Wear protective clothing (permethrin impregnated clothing)	Reduced incidence of tick bites	March 2009 - Sep2009	varies

		for the prevention of tick bites				
D	Maloney EL	The management of Ixodes scapularis bites in the upper Midwest	Prophylactic treatment: administer appropriate antibiotics soon after tick bites	Inconclusive.	NA	NA

**Category A = Reduce overall tick density; Category B = Lower the prevalence of infection with B. burgdorferi in reservoir hosts and/or host-seeking ticks; Category C = Modify human behavior to reduce exposure to ticks and prevent transmission by prompt removal of attached ticks; Category D = Prevent Lyme disease by vaccination against B. burgdoreferi or prophylactic treatment after bite*

Appendix B: Key Informant Interview Guide

Interview guide for County Health Officers

Background

1. Please confirm your title.
2. How long have you been in this position?
3. In general, what is your preferred source of information on control and prevention practices for Lyme disease or other tick-borne infections? (probe on whether they go to any websites)

Perceptions of State and County Health Department Practices

4. To the best of your knowledge, which State government agencies are (currently?) involved in the coordination of Tick-borne disease control and prevention?
5. To the best of your knowledge, what kinds of services are provided by State agencies with regards to the control and prevention of tick-borne diseases, specifically for Lyme disease?
6. To the best of your knowledge, which County government agencies are (currently?) involved in the coordination of Tick-borne disease control and prevention?
7. To the best of your knowledge, what kinds of services are provided by the county health department with regards to the control and prevention of tick-borne diseases, specifically for Lyme disease?
8. In your opinion, what are the most effective ways to control tick populations?
9. In your opinion, what are the most effective ways to prevent Lyme disease?

Perceptions of Community-based practices

10. Besides State and county governments, are there other groups that are participating in Lyme disease control and prevention activities in your County? This may include but not limited to other public or private sector organizations or businesses (examples: churches, schools, non-profit organizations, private businesses, clubs, camps, park associations, civic associations, commercial businesses, or independent researchers)? *probe to provide specific examples for following:*
    - *a.* Camps:
    - b. Churches:
    - c. Civic Associations:
    - d. Clubs:
    - *e.* Commercial businesses (e.g. Pest Control businesses, Landscapers, etc*.):*

f. Government Agencies:
g. Independent researchers:
h. Non-profit organizations:
i. Park Association:
j. Private businesses: (e.g. Walmart, Safeway, etc.)
k. Schools:
l. Other:

If yes, please provide as much detail as to the nature of the activities by these other groups

11. In general, do you think communities can significantly decrease transmission of Lyme disease ? (Y/N) *Please explain*
12. Are there certain groups or organizations that should be involved in tick control and Lyme disease prevention but are not? Who are they?
13. Please describe the role that these additional organizations should play.
14. In your opinion, should there be a standard community approach to follow to control and prevent Lyme disease in high risk areas? If Yes, please describe the approach and who should be responsible for its coordination and implementation. If No, please describe the approach that should be applied and who would be responsible for its coordination and implementation.
15. What prevention and control activities would you like to see implemented in your county that are currently not available?
16. Are there any other issues or concerns you think are important to mention with regards to Lyme disease control and prevention in your county or elsewhere?

Appendix C: Public / Private Sector Survey

Tick Control and Lyme Disease Prevention Survey

1) What best describes your organization? [type] Would you say….. (chose one):
   - ☐ Camp?
   - ☐ Civic Association?
   - ☐ Commercial business?
   - ☐ Government Agency?
   - ☐ Independent research?
   - ☐ Non-profit organization?
   - ☐ Park Association?
   - ☐ Private business?
   - ☐ Religious?
   - ☐ School?
   - ☐ Other(Please specify) [type_other]:_____

2) In general, do you think Lyme disease can be prevented [transmission]?
   - ☐ Yes
   - ☐ No

3) During the past 5 years has your organization participated in any tick-control or Lyme disease prevention activities? (select all the apply):
   - ☐ health education (avoid high-risk habitats during peak transmission season, conduct regular tick checks (removal of ticks within < 24 hrs after attachment), wear appropriate/protective clothing, etc.) [activity1]
   - ☐ application of area-wide insecticides (natural or synthetic) to reduce tick populations [activity2]
   - ☐ treatment of rodent host species with insecticides (e.g, bait boxes, permethrin-treated cotton balls) [activity3]
   - ☐ treatment of deer host species with insecticides (e.g, 4-poster device) [activity4]
   - ☐ landscape management (e.g. bordering, use of cedar mulch) [activity5]
   - ☐ use of fencing to prevent contact with wildlife [activity6]
   - ☐ reduction of deer populations (e.g. hunting, sterilization) [activity7]
   - ☐ Other [activity*8*] (please specify) [activity_other]:_____
   - ☐ Organization did not participate in any tick control or Lyme disease prevention activities in past 5 years [no_participation]

     If your organization did not participated in any of these activities, please explain why (select all that apply) - *provide reasons below then go to qx.7*
     - ☐ Other organizations were already involved [reason1]

please specify names of other organizations [reason1_specific]:

_____

_____

- Our organization didn't have the capacity [reason2]
- Not aware that organizations could support these activities [reason3]
- Resources were not available to participate [reason4]
- Other [reason5] (please specify) [reason5_specific]:_____

For **each** of the activities selected please answer the following questions 4a-h:

4) Activity [activity1, activity2, ……, activityn]: _____

- Please briefly describe activity, including any health education or behavior change messages if any [description]:

  _____

  _____

  _____

- Did your organization target this activity to a specific demographic or social group (age, gender, profession, etc.) [target]?
  - Yes
  - No

  If Yes, please specify which group(s) [target_specify]:_____

- Please specify the year(s) in which your organization participated in this activity:
  - 2008 [year_08]
  - 2009 [year_09]
  - 2010 [year_10]
  - 2011 [year_11]
  - 2012 [year_12]
  - 2013 [year_13]
- Were there specific month(s) that the activity was targeted? If so please check which months:
  - Jan [month1]
  - Feb [month2]
  - Mar [month3]
  - Apr [month4]
  - May [month5]
  - Jun [month6]
  - Jul [month7]
  - Aug [month8]
  - Sep [month9]
  - Oct [month10]
  - Nov [month11]

- Dec [month12]

- How often was the activity repeated during the months selected [frequency] (choose one):
  - Daily
  - Once per week
  - Once per month
  - Other [frequency_other]: _____
- Please provide as much information on the locations that benefitted from the activity (town(s), zip codes, counties, etc.)[coverage]:

  _____
  _____
  _____
- What financial resources were use in order to implement activities? (select all that apply)
  - Federal funds [funding1]
  - State funds [funding2]
  - Private funds[funding3]
  - Research grant [funding4]
  - Volunteer based [funding5]
  - Fee for service [funding6]
  - Other [funding7] (please specify) [funding_other]:_____
  - I don't recall [funding7]
- What is the approximate amount ($) spent by your organization **per year** to promote this particular activity [cost]? (choose one)
  - < $100 dollars
  - $100 - $499
  - $500 - $1,000
  - $1,000 - $1,500
  - $1,500 - $2,000
  - Other (please specify) [cost_other]:_____
  - I don't recall

5) Briefly explain why your organization participated in these activities [participation]?

_____
_____
_____

6) Are there written reports that you can share documenting the tick control or Lyme disease prevention activities you participated in [reports]?
   - Yes - Please note down how to access [reports_access]:_____
   - No

- ☐ I don't know

7) Which of the following tick-control or Lyme disease prevention activities is your organization most interested in participating in (select all that apply)
   - ☐ Provide health education (avoid high-risk habitats during peak transmission season, conduct regular tick checks (removal of ticks within < 24 hrs after attachment), wear appropriate/protective clothing, etc.) [interest1]
   - ☐ Promote application of area-wide insecticides (synthetic pyrethroids) to reduce tick populations [interest2]
   - ☐ Promote application of area-wide insecticides (Natural Organic Compounds) to reduce tick populations [interest3]
   - ☐ Promote treatment of rodent host species with insecticides (e.g, bait boxes, permethrin-treated cotton balls) [interest4]
   - ☐ Promote treatment of deer host species with insecticides (e.g., 4-poster device) [interest5]
   - ☐ Promote landscape management (e.g. bordering, use of cedar mulch) [interest6]
   - ☐ Promote the use of fencing to prevent contact with wildlife [interest7]
   - ☐ Promote reduction of deer populations (e.g. hunting, sterilization) [interest8]
   - ☐ Other [interest9] (please specify) [interest_other]:_____
   - ☐ Our organization does not have the capacity (resources) to participate [interest10]
   - ☐ Our organization does not want to participate in tick control activities [interest11]

8) What would make organizations more likely to be involved in tick-control or Lyme disease control and prevention activities? (select all the apply)
   - ☐ Additional guidance and training [involvement1]
   - ☐ Additional financial resources [involvement2]
   - ☐ Better publicity of these activities [involvement3]
   - ☐ Knowledge of that Lyme disease risk in community is High [involvement4]
   - ☐ Other involvement [involvement5] (please specify) [involvement5_other]:_____

9) Over the past 5 years what sources of information have encouraged you to participate in tick control and Lyme disease prevention activities? (select all the apply)
   - ☐ Organization(s)/ Departments(s) [info1] (please specify) [info1_specify]: _____
   - ☐ Website [info2] (please specify website) [info2_specify]: _____
   - ☐ Radio [info3]
   - ☐ Television [info4]
   - ☐ Posters [info5]
   - ☐ Brochures [info6]

- ☐ Other [info7](please specify): _____
- ☐ I don't recall [info8]

10) Can you think of other ways that control and prevention activities can be improved [other_improved]?
    - ☐ Yes – please specify other approaches[improved_details]:
      _____
      _____
      _____
      _____
    - ☐ No
11) Can we contact you for addition information if needed [information]?
    - ☐ Yes
    - ☐ No

REFERENCES

Allan, C., & Stankey, G. (2009). *Adaptive Environmental Management: A practitioner's guide.* Dordrecht: Springer.

Alao, O. R., & Decker, C. F. (2012). Lyme disease. *Disease-a-Month : DM, 58*(6), 335-345. doi: 10.1016/j.disamonth.2012.03.005

Anderson, J. F., & Magnarelli, L. A. (1980). Vertebrate host relationships and distribution of ixodid ticks (acari: Ixodidae) in connecticut, USA. *Journal of Medical Entomology, 17*(4), 314-323.

Beard, C. B., & Strickman, D. (2014). *Federal Initiative: Tick-Borne Disease Integrated Pest Management White Paper.*

Bhattacharya, D., Bensaci, M., Luker, K. E., Luker, G., Wisdom, S., Telford, S. R., & Hu, L. T. (2011). Development of a baited oral vaccine for use in reservoir-targeted strategies against lyme disease. *Vaccine, 29*(44), 7818-7825. doi: 10.1016/j.vaccine.2011.07.10

Bolognia, J. L., Jorizzo, J. L., & Rapini, R. P. (2007). *Dematology (2nd ed.).* St.Louis: Mosby.

Brei, B., Brownstein, J. S., George, J. E., Pound, J. M., Miller, J. A., Daniels, T. J., . . . Fish, D. (2009). Evaluation of the united states department of agriculture northeast area-wide tick control project by meta-analysis. *Vector Borne and Zoonotic Diseases (Larchmont, N.Y.), 9*(4), 423-430. doi: 10.1089/vbz.2008.0150

Burgdorfer, W., A. G. Barbour, S. F. Hayes, J. L. Benach, E. Grunwaldt, & and J. P. Davis. (1982). Lyme disease: A tick-borne spirochetosis. *Science (New York, N.Y.) JID - 0404511, 216*, 1317.

Carroll, J. F., Pound, J. M., Miller, J. A., & Kramer, M. (2009). Sustained control of gibson island, maryland, populations of ixodes scapularis and amblyomma americanum (acari: Ixodidae) by community-administered 4-poster deer self-treatment bait stations. *Vector Borne and Zoonotic Diseases (Larchmont, N.Y.), 9*(4), 417-421. doi: 10.1089/vbz.2008.0166CDC. (2012). 2012 Case Definitions: Nationally Notifiable Conditions Infectious and Non-Infectious Case. Atlanta, Ga.

Centers for Disease Control and Prevention. (2012). 2012 case definitions: Nationally notifiable conditions infectious and non-infectious case. Atlanta, GA.

Centers for Disease Control and Prevention. (January 11, 2013). Lyme disease surveillance and available data. Retrieved March 6, 2013, from http://www.cdc.gov/lyme/stats/survfaq.html

Centers for Disease Control and Prevention. (June 15, 2007). Lyme disease — united states, 2003–2005. *MMWR 2007, 56*(23), 573.

Centers for Disease Control and Prevention. (May 13, 2011). Summary of notifiable diseases—United states, 2009. *MMWR 2009, 58*(53)

Centers for Disease Control and Prevention. National Center for Emerging and Zoonotic Infectious Diseases (NCEZID) Division of Vector-Borne Diseases (DVBD). (November 15, 2011). Signs and symptoms of lyme disease. Retrieved Oct, 2012, from http://www.cdc.gov/lyme/signs_symptoms/index.html

Centers for Disease Control and Prevention. Lyme disease prevention and control activities: Connecticut Department of Public Health and the Connecticut Attorney General's Office, (2004).

Christina Frank, A. D. (2002). Mapping Lyme Disease Incidence for Diagnostic and Preventive Decisions, Maryland. *Emerging Infectious Diseases, 8*(4).

Clark, R. P., & Hu, L. T. (2008). Prevention of lyme disease and other tick-borne infections. *Infectious Disease Clinics of North America, 22*(3), 381-96, vii. doi: 10.1016/j.idc.2008.03.007

Connally, N. P., Durante, A. J., Yousey-Hindes, K. M., Meek, J. I., Nelson, R. S., & Heimer, R. (2009). Peridomestic lyme disease prevention: Results of a population-based case-control study. *American Journal of Preventive Medicine, 37*(3), 201-206. doi: 10.1016/j.amepre.2009.04.026County Health Rankings. (2014). Retrieved from http://www.countyhealthrankings.org/

Coyle, B. S., Strickland, G. T., Liang, Y. Y., Pena, C., McCarter, R., & Israel, E. (1996). The public health impact of lyme disease in maryland. *The Journal of Infectious Diseases, 173*(5), 1260-1262.Diuk-Wasser MA, H. A. (2012). Human Risk of Infection with Borrelia burgdorferi, the Lyme Disease Agent, in Eastern United States. *Am J Trop Med Hyg., 86*(2).

Curran, K. L., Fish, D., & Piesman, J. (1993). Reduction of nymphal ixodes dammini (acari: Ixodidae) in a residential suburban landscape by area application of insecticides. *Journal of Medical Entomology, 30*(1), 107-113.

Daltroy, L. H., Phillips, C., Lew, R., Wright, E., Shadick, N. A., & Liang, M. H. (2007). A controlled trial of a novel primary prevention program for lyme disease and other tick-borne illnesses. *Health Education & Behavior : The Official Publication of the Society for Public Health Education, 34*(3), 531-542. doi: 10.1177/1090198106294646

Diuk-Wasser, M. A., Hoen, A. G., Cislo, P., Brinkerhoff, R., Hamer, S. A., Rowland, M., . . . Fish, D. (2012). Human risk of infection with borrelia burgdorferi, the lyme disease agent, in eastern united states. *The American Journal of Tropical Medicine and Hygiene, 86*(2), 320-327. doi: 10.4269/ajtmh.2012.11-0395; 10.4269/ajtmh.2012.11-0395

Dolan, M. C., Jordan, R. A., Schulze, T. L., Schulze, C. J., Manning, M. C., Ruffolo, D., . . . Karchesy, J. J. (2009). Ability of two natural products, nootkatone and carvacrol, to suppress ixodes scapularis and amblyomma americanum (acari: Ixodidae) in a lyme disease endemic area of new jersey. *Journal of Economic Entomology, 102*(6), 2316-2324.

Dolan, M. C., Maupin, G. O., Schneider, B. S., Denatale, C., Hamon, N., Cole, C., . . . Stafford, K. C.,3rd. (2004). Control of immature ixodes scapularis (acari: Ixodidae) on rodent reservoirs of borrelia burgdorferi in a residential community of southeastern connecticut. *Journal of Medical Entomology, 41*(6), 1043-1054.

Dolan, M. C., Schulze, T. L., Jordan, R. A., Dietrich, G., Schulze, C. J., Hojgaard, A., . . . Piesman, J. (2011). Elimination of borrelia burgdorferi and anaplasma phagocytophilum in rodent reservoirs and ixodes scapularis ticks using a doxycycline hyclate-laden bait. *The American Journal of Tropical Medicine and Hygiene, 85*(6), 1114-1120. doi: 10.4269/ajtmh.2011.11-0292

Drymon, M. M. (2008). *Disguised as the Devil: how Lyme disease ceated witches and changed history.* Wythe Avenue Press.

Eisen, R. J., Lane, R. S., Fritz, C. L., & Eisen, L. (2006). Spatial patterns of lyme disease risk in california based on disease incidence data and modeling of vector-tick exposure. *The American Journal of Tropical Medicine and Hygiene, 75*(4), 669-676.

Eisen, R. J., Piesman, J., Zielinski-Gutierrez, E., & Eisen, L. (2012). What do we need to know about disease ecology to prevent lyme disease in the northeastern united states? *Journal of Medical Entomology, 49*(1), 11-22.

Fell, E. (2000). An update on Lyme disease and other tick-borne illnesses. *Nurse Pract.*, 25, 10, 38-40, 43-4, 47-8.

Fix, A. D., Strickland, T., & Grant, J. (1998). Tick bites and Lyme disease in an endemic setting. *JAMA*, 279:206-10.

Frank, C., Fix, A. D., Pena, C. A., & Strickland, G. T. (2002). Mapping lyme disease incidence for diagnostic and preventive decisions, maryland. *Emerging Infectious Diseases, 8*(4), 427-429. doi: 10.3201/eid0804.000413

Hoen, A. G., Margos, G., Bent, S. J., Diuk-Wasser, M. A., Barbour, A., Kurtenbach, K., et al. (2009). Phylogeography of Borrelia burgdorferi in the eastern United States reflects multiple independent Lyme disease emergence events. *Proc. Natl. Acad. Sci.*, 15013-8.

Holling, C. (1978). *Adaptive Environmental Assessment and Management.* Wiley London: Blackburn Press.

Hornbostel, V. L., Ostfeld, R. S., & Benjamin, M. A. (2005). Effectiveness of metarhizium anisopliae (deuteromycetes) against ixodes scapularis (acari: Ixodidae) engorging on peromnyscus leucopus. *Journal of Vector Ecology: Journal of the Society for Vector Ecology, 30*(1), 91-101.

Joseph Piesman, L. E. (2008). Prevention of Tick-Borne Diseases. *Annual Review of Entomology, Vol. 53: 323-343* .

Garnett, J. M., Connally, N. P., Stafford, K. C.,3rd, & Cartter, M. L. (2011). Evaluation of deer-targeted interventions on lyme disease incidence in connecticut. *Public Health Reports (Washington, D.C.: 1974), 126*(3), 446-454.

Glass, G. E., Schwartz, B. S., Morgan, J. M.,3rd, Johnson, D. T., Noy, P. M., & Israel, E. (1995). Environmental risk factors for lyme disease identified with geographic information systems. *American Journal of Public Health, 85*(7), 944-948.

Golaine, A. (2011). Natural health is our DNA. Retrieved May/5, 2012, from http://www.encognitive.com/node/5769Kuehn, B. M. (2013). CDC Estimates 300 000 US Cases of Lyme Disease Annually. *JAMA*, 310(11):1110.

Johnson, L., Aylward, A., & Stricker, R. B. (2011). Healthcare access and burden of care for patients with lyme disease: A large united states survey. *Health Policy (Amsterdam, Netherlands), 102*(1), 64-71. doi: 10.1016/j.healthpol.2011.05.007

Jordan, R. A., Dolan, M. C., Piesman, J., & Schulze, T. L. (2011). Suppression of host-seeking ixodes scapularis and amblyomma americanum (acari: Ixodidae) nymphs after dual applications of plant-derived acaricides in new jersey. *Journal of Economic Entomology, 104*(2), 659-664.

Jordan, R. A., Schulze, T. L., & Jahn, M. B. (2007). Effects of reduced deer density on the abundance of ixodes scapularis (acari: Ixodidae) and lyme disease incidence in a northern new jersey endemic area. *Journal of Medical Entomology, 44*(5), 752-757.

Leger, E., Vourc'h, G., Vial, L., Chevillon, C., & McCoy, K. (2013). Changing distributions of ticks: causes and consequences. *Exp.Appl.Acarol.*, 59, 1-2, 219-244.

LoGiudice, K., Ostfeld, R. S., Schmidt, K. A., & Keesing, F. (2003). The ecology of infectious disease: Effects of host diversity and community composition on lyme disease risk. *Proceedings of the National Academy of Sciences of the United States of America, 100*(2), 567-571. doi: 10.1073/pnas.0233733100

Lorraine Johnson, A. A. (2011). Healthcare access and burden of care for patients with Lyme disease: A large United States survey. *Health Policy*.

Maloney, E. L. (2011). The management of ixodes scapularis bites in the upper midwest. *WMJ : Official Publication of the State Medical Society of Wisconsin, 110*(2), 78-81; quiz 85.

Maria A. Diuk-Wasser, G. V. (July 2010). Field and climate-based model for predicting the density of host-seeking nymphal Ixodes scapularis, an important vector of tick-borne disease agents in the eastern United States. *Global Ecology and Biogeography, 19*(4).

Mather, T. N., Wilson, M. L., Moore, S. I., Ribeiro, J. M., & Spielman, A. (1989). Comparing the relative potential of rodents as reservoirs of the lyme disease spirochete (borrelia burgdorferi). *American Journal of Epidemiology, 130*(1), 143-150.

Mather, T. (n.d.). *Tick-bite prevention*. Retrieved September 6, 2014, from Tick Encounter Resource Center: http://www.tickencounter.org/faq/tick_bite_prevention

Mathew C Nicholson, T. N. (1996). Methods for Evaluating Lyme Disease Risks Using Geographic Information Systems and Geospatial Analysis . *Journal of Medical Entomology, 33*(5).

Mead, P. (2004). Hearing: CDC's Lyme Disease Prevention and Control Activities. *onnecticut Department of Public Health and the Connecticut Attorney General's Office.*

MEASURE Evaluation PRH. (n.d.). *Behavior Change Communication*. Retrieved August 1, 20014, from http://www.cpc.unc.edu/measure/prh/rh_indicators/crosscutting/bcc

Meltzer, M. I., Dennis, D. T., & Orloski, K. A. (1999). The cost effectiveness of vaccinating against Lyme disease. *Emerging Infectious Diseases*, 321-328.

Nadelman, R. B., Nowakowski, J., Fish, D., Falco, R. C., Freeman, K., McKenna, D., . . . Tick Bite Study Group. (2001). Prophylaxis with single-dose doxycycline for the prevention of lyme disease after an ixodes scapularis tick bite. *The New England Journal of Medicine, 345*(2), 79-84. doi: 10.1056/NEJM200107123450201

National Center for Health Statistics. (2012). *Healthy People 2010 Final Review.* Hyatsville, MD.

Neelakanta, G., Sultana, H., Fish, D., Anderson, J. F., & Fikrig, E. (2010). Anaplasma phagocytophilum induces ixodes scapularis ticks to express an antifreeze glycoprotein gene that enhances their survival in the cold. *The Journal of Clinical Investigation, 120*(9), 3179-3190. doi: 10.1172/JCI42868; 10.1172/JCI42868

Nicholson, M. C., & Mather, T. N. (1996). Methods for evaluating lyme disease risks using geographic information systems and geospatial analysis. *Journal of Medical Entomology, 33*(5), 711-720.

Ostfeld, R. S., Schauber, E. M., Canham, C. D., Keesing, F., Jones, C. G., & Wolff, J. O. (2001). Effects of acorn production and mouse abundance on abundance and borrelia burgdorferi infection prevalence of nymphal ixodes scapularis ticks. *Vector Borne and Zoonotic Diseases (Larchmont, N.Y.), 1*(1), 55-63.

Padgett, K. A., Casher, L. E., Stephens, S. L., & Lane, R. S. (2009). Effect of prescribed fire for tick control in california chaparral. *Journal of Medical Entomology, 46*(5), 1138-1145.

Patrican, L. A., & Allan, S. A. (1995). Application of desiccant and insecticidal soap treatments to control ixodes scapularis (acari: Ixodidae) nymphs and adults in a hyperendemic woodland site. *Journal of Medical Entomology, 32*(6), 859-863.

Pepin, K. M., Eisen, R. J., Mead, P. S., Piesman, J., Fish, D., Hoen, A. G., . . . Diuk-Wasser, M. A. (2012). Geographic variation in the relationship between human lyme disease incidence and density of infected host-seeking ixodes scapularis nymphs in the eastern united states. *The American Journal of Tropical Medicine and Hygiene, 86*(6), 1062-1071. doi: 10.4269/ajtmh.2012.11-0630; 10.4269/ajtmh.2012.11-0630

Piesman, J. (1989). Transmission of lyme disease spirochetes (borrelia burgdorferi). *Experimental & Applied Acarology, 7*(1), 71-80.

Piesman, J., & Eisen, L. (2008). Prevention of tick-borne diseases. *Annual Review of Entomology, 53*, 323-343. doi: 10.1146/annurev.ento.53.103106.093429

Poland, G. A. (2011). Vaccines against lyme disease: What happened and what lessons can we learn? *Clinical Infectious Diseases : An Official Publication of the Infectious Diseases Society of America, 52 Suppl 3*, s253-8. doi: 10.1093/cid/ciq116

Pound, J. M., Miller, J. A., George, J. E., Fish, D., Carroll, J. F., Schulze, T. L., . . . Mather, T. N. (2009). The united states department of agriculture's northeast area-wide tick control project: Summary and conclusions. *Vector Borne and Zoonotic Diseases (Larchmont, N.Y.), 9*(4), 439-448. doi: 10.1089/vbz.2008.0200

Prevention, C. f. (2011, April 12). *Lyme disease*. (National Center for Emerging and Zoonotic Infectious Diseases (NCEZID), Division of Vector-Borne Diseases (DVBD)) Retrieved Feb 24, 2012, from Centers for Disease Control and Prevention: http://www.cdc.gov/lyme/prev/on_people.html

Prevention, C. f. (May 13, 2011). Summary of notifiable diseases—United States, 2009. *MMWR 2009(58 (53))*.

Rand, P. W., Lubelczyk, C., Holman, M. S., Lacombe, E. H., & Smith, R. P.,Jr. (2004). Abundance of ixodes scapularis (acari: Ixodidae) after the complete removal of deer from an isolated offshore island, endemic for lyme disease. *Journal of Medical Entomology, 41*(4), 779-784.

Rebecca J. Eisen, R. S. (2006). Spatial Patterns of Lyme Disease Risk in California Based on Disease Incidence Data and Modeling of Vector-Tick Exposure . *Am J Trop Med Hyg, 75*(4).

Richard S. Ostfeld, F. K. (June 2000). Biodiversity and Disease Risk: the Case of Lyme Disease. *Conservation Biology, 14*(3).

Schulze, T. L., Taylor, G. C., Vasvary, L. M., Simmons, W., & Jordan, R. A. (1992). Effectiveness of an aerial application of carbaryl in controlling ixodes dammini (acari: Ixodidae) adults in a high-use recreational area in new jersey. *Journal of Medical Entomology, 29*(3), 544-547.

Schulze, T. L., Jordan, R. A., Healy, S. P., Roegner, V. E., Meddis, M., Jahn, M. B., & Guthrie DL, S. (2006). Relative abundance and prevalence of selected borrelia infections in ixodes scapularis and amblyomma americanum (acari: Ixodidae) from publicly owned lands in monmouth county, new jersey. *Journal of Medical Entomology, 43*(6), 1269-1275.

Schulze, T., & Jordan, R. A. (2006). *Assessment and management of vector tick poulations in New Jersey.* Frehold Township Health Department, Hightstown, N.J.: Freehold Township Health Department.

Schwartz, B. (2012, March 27). *Johns Hopkins Arthritis Center*. Retrieved September 04, 2014, from http://www.hopkinsarthritis.org/arthritis-info/lyme-disease/lyme-disease-controversies/

Stafford, K. C. (2004). *Tick Management Handbook: A integrated guide for homeowners.* Retrieved Feb 24, 2012, from http://www.ct.gov/caes/lib/caes/documents/special_features/tickhandbook.pdf

Stafford, K. C.,3rd, & Allan, S. A. (2010). Field applications of entomopathogenic fungi beauveria bassiana and metarhizium anisopliae F52 (hypocreales: Clavicipitaceae) for the control of ixodes scapularis (acari: Ixodidae). *Journal of Medical Entomology, 47*(6), 1107-1115.

Steere, A. C., McHugh, G., Damle, N., & Sikand, V. K. (2008). Prospective study of serologic tests for lyme disease. Clinical Infectious Diseases : An Official Publication of the Infectious Diseases Society of America, 47(2), 188-195. doi: 10.1086/589242; 10.1086/589242

Strei, K., & Colella, S. (2010). Developing Leaders' Networks Through a Stakeholder Mapping and Engagement Workshop. In R. Cross, J. Singer, S. Colella, R. Thomas, & Y. Silverstone, *The Organizational Network Fieldbook* (pp. 282-290). Jossey-Bass.

Tonks, A. (2007). Lyme wars. *BMJ (Clinical Research Ed.), 335*(7626), 910-912. doi: 10.1136/bmj.39363.530961.AD

Tsao, J. I., Wootton, J. T., Bunikis, J., Luna, M. G., Fish, D., & Barbour, A. G. (2004). An ecological approach to preventing human infection: Vaccinating wild mouse reservoirs intervenes in the lyme disease cycle. *Proceedings of the National Academy of Sciences of the United States of America, 101*(52), 18159-18164. doi: 10.1073/pnas.0405763102

Vaughn, M. F., & Meshnick, S. R. (2011). Pilot study assessing the effectiveness of long-lasting permethrin-impregnated clothing for the prevention of tick bites. *Vector Borne and Zoonotic Diseases (Larchmont, N.Y.), 11*(7), 869-875. doi: 10.1089/vbz.2010.0158

Vazquez, M., Muehlenbein, C., Cartter, M., Hayes, E. B., Ertel, S., & Shapiro, E. D. (2008). Effectiveness of personal protective measures to prevent lyme disease. *Emerging Infectious Diseases, 14*(2), 210-216. doi: 10.3201/eid1402.070725

Volkman, D. (2007). Prophylaxis after tick bites. *Lancet Infectious Diseases*, 370-371.

Wormser, G. P., Dattwyler, R. J., Shapiro, E. D., Halperin, J. J., Steere, A. C., Klempner, M. S., et al. (2006). The clinical assessment, treatment, and prevention of Lyme disease, human granulocytic anaplasmosis, and babesiosis: clinical practice guidelines by the infectious diseases society of America. *Clin Infect Dis*, 43(9):1089-134.

Zhang, X., Meltzer, M. I., Pena, C. A., Hopkins, A. B., Wroth, L., & Fix, A. D. (2006). Economic impact of lyme disease. *Emerging Infectious Diseases, 12*(4), 653-660. doi: 10.3201/eid1204.050602