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Lyme Disease in the Northeast: Altered Ecosystems and Public Health Impacts

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Lyme Disease in the Northeast: Altered Ecosystems and Public Health Impacts

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Abstract

Lyme disease has spread rapidly throughout the United States since its original discovery in 1975. An increasing threat to public health, this common vector-borne disease is transferred to a human after receiving a bite from an infected blacklegged tick (*Ixodes scapularis*). Humans have contributed to the massive influx of tick populations and Lyme disease cases through the introduction of invasive flora and fauna, overhunting of apex predators, and altering areas of land for urbanization. Quantitative data from the CDC and USDA on Lyme disease cases and white-tailed deer populations in the United States demonstrates the impact of human disruption of delicate ecosystems. My research at the Fordham University Louis Calder Biological Field Station is used as a case study on the impact of the presence of invasive Japanese Barberry (*Berberis thunbergii*) on plant biodiversity, and blacklegged tick densities. Invasive flora lack natural predators and are therefore able to outcompete native plant species, while creating suitable habitat for ticks. The natural and social science disciplines used to address this issue include public health, environmental history, and conservation biology. Mitigation policy solutions for this major environmental and public health issue have been tried in various geographies throughout the Northeast with limited and varying degrees of effectiveness. These policies include land management and reduction of tick habitat, invasive plant control, increased hunting of white-tailed deer, and the use of biocontrol organisms such as parasitic wasps and fungi. Given the limitation of habitat-based solutions, effective adaptation policy solutions have been developed over many years and include increased public awareness and education on proper outdoor clothing, tick removal, insect repellants, and the need for a Lyme disease vaccine for humans.
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Introduction: Why Care About Lyme disease?

Lyme disease is an infectious vector-borne disease that is caused by *B. burgdorferi* bacteria. It is transferred to humans following a bite from a blacklegged tick.\(^1\) Lyme disease has been a growing public health issue in the United States since the 1970s following its discovery in Lyme, Connecticut.\(^2\) The threat of contracting Lyme disease is highest in the temperate northeastern United States, where the most cases are recorded each year. Although typically not life threatening, if left untreated, this disease can lead to long-term debilitating effects on the joints, heart, and nervous system.\(^3\) Tick populations are increasing, along with their primary hosts, the white-tailed deer, and the white-footed mouse.\(^4\) As tick populations have grown, the chances of a person contracting Lyme disease have risen, especially in certain geographies. More attention needs to be focused on the environmental changes that have allowed for this rise in infectious disease, as well as the necessary steps needed in to slow the spread of Lyme.

This study illustrates how changing the environment can lead to serious environmental and public health issues for humans and ecosystems in the future. It emphasizes how historical land-use practices created changes that have impacted the temperate forest ecosystems of the northeastern United States. It specifically discusses how the alterations made to the land have diminished biodiversity levels and ecosystem services, and these repercussions have contributed to the rise in Lyme disease and large tick populations that exist today. The study of the spread of Lyme disease demonstrates how all changes in the environment create a domino effect.

Disturbances in the environment radiate throughout the ecosystem and impact each of its members, including humans. Many people forget that they are, in fact, a part of the ecosystems that they live in. That is why it is important for humans to be conscious of how they treat the environment. Making small modifications may not appear to cause immediate or drastic impacts. It is crucial that people understand that every disturbance that they create can lead to serious environmental and public health problems for generations in the future. This study provides information on a contemporary environmental issue that can inspire people to think about the future repercussions before interfering with the world’s ecosystems.

Chapter 1 provides current statistical and quantitative data from the CDC and USDA. The data provides information on the increase in diagnoses of Lyme disease over time, the geographic distribution of reported cases, and on Japanese barberry and white-tailed deer populations. This chapter illustrates the gravity of the Lyme disease epidemic, and puts the severity of this environmental issue into perspective.

Chapter 2 provides information and examples of the widespread impact of Lyme disease on public health. I first briefly discuss how and when Lyme disease was discovered. The following pages in the chapter describe how Lyme disease is transmitted from tick to human, the initial signs and symptoms of an infection, and the long-term health impacts in humans. I also elaborate on the careful diagnostic process, as well as the different methods of treatment for Lyme disease.

Chapter 3 uses environmental history to explain the increasing spread of Lyme disease that it is taking place in the northeastern United States. In this chapter, I talk about both Native American and colonist land-use practices that led to clearing of the land, and exhaustion of the forests’ resources. I also discuss how Native Americans and colonists overhunted white-tailed
deer and apex predators, and depleted their populations. The end of the chapter describes the reforestation of the land in the Northeast following westward expansion in the 1800s.

Chapter 4 uses conservation biology to discuss the tick life cycle, as well as the importance of the white-tailed deer and the white-footed mouse to the spread of Lyme disease. I talk about how the historical land-use practices changed the northeastern forests today into ideal habitat for ticks and their hosts. This chapter also discusses invasive plant species and their role in boosting tick populations and increasing the spread of Lyme disease. I provide a case study from research I conducted at the Fordham University Louis Calder Center on the association between the presence of Japanese barberry, and high densities of blacklegged ticks. I use this case study to illustrate how changes in the land reduce biodiversity and ecosystem services, which contributes to the spread of infectious diseases, like Lyme. The end of the chapter talks about how climate change is increasing the geographic distribution of ticks and their hosts, and is therefore contributing to the spread of Lyme disease throughout North America.

Chapter 5 provides examples of possible mitigation and adaptation solutions to the Lyme disease problem. In terms of mitigation, I discuss strategies for managing the land, animal populations, invasive plant populations, and organisms that could be used for biocontrol. For adaptation solutions, I discuss how people can decrease their chances of being bitten and contracting Lyme disease through the use of proper clothing, tick removal techniques, insect repellents, and Lyme vaccines.
Chapter 1. A Growing Threat

Lyme disease is the most commonly reported vector-borne disease in the United States. Over 10,000 people are diagnosed with Lyme disease in the Northeast every year, although there are still some cases that go without being diagnosed. Tick populations and Lyme disease cases have been increasing each year ever since its discovery in 1975. It is most common in the Northeast. In 2013, 95 percent of confirmed Lyme disease cases were reported from a total of fourteen states including Connecticut, Delaware, Maine, Maryland, Massachusetts, Minnesota, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia, and Wisconsin. According to the CDC, in 2013, there were 2,111 confirmed cases of Lyme disease in Connecticut, 1,127 in Maine, 3,816 in Massachusetts, 1,324 in New Hampshire, 2,785 in New Jersey, 3,512 in New York, and 4,981 in Pennsylvania. Lyme disease diagnoses have been increasing steadily over time since the beginning of their recording in 1995. In 1995, there were just of 10,000 diagnosed cases of Lyme disease in the United States. By 2013, there were over 35,000 people diagnosed. Lyme disease is most commonly diagnosed in children of ages ranging from infancy to fifteen years old. It is also commonly diagnosed in adults in their forties and fifties. This trend is believed to occur because people of these age groups spend the most time outdoors. Most people are diagnosed with Lyme disease anytime between May and August because these are the months when the tick nymphs are questing for a meal. States with a lower diversity of native vegetation and apex predators were recorded as having higher

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9 Centers for Disease Control and Prevention, “CDC.”
10 Centers for Disease Control and Prevention, “CDC.”
numbers of Lyme disease cases. Therefore, Lyme disease risk decreases with higher levels of biodiversity.\textsuperscript{11} Figure 1 illustrates the increase in reported cases of Lyme disease from 2001 to 2013.

![Figure 1: Reported cases of Lyme disease in the U.S. in 2001 (left), and reported cases of Lyme disease in the U.S. in 2013 (right).\textsuperscript{12}](image)

The white-tailed deer population today is made up of approximately 30 million animals throughout the United States. There is believed to be approximately twenty deer per square mile in the Northeast. These high white-tailed deer populations are providing a larger food supply to blacklegged ticks.\textsuperscript{13} The spread of invasive flora is providing more suitable habitat for ticks, and may result in higher tick densities.

Invasive Japanese barberry typically grows in areas previously used as agricultural land. It has been observed that there are higher densities of blacklegged ticks in areas with high concentrations of Japanese barberry. It is estimated that there are approximately 280 infected

\textsuperscript{12} Centers for Disease Control and Prevention, “CDC.”
\textsuperscript{13} U.S. Department of Health and Human Services. “Lyme Disease.”
ticks per hectare in areas of land with Japanese barberry infestations. The number of infected ticks decreases by sixty percent following the removal of Japanese barberry.\textsuperscript{14}

The prevalence at which Lyme disease exists today is due, in part, to land clearing that took place during the seventeenth and eighteenth centuries. Approximately 60 to 80 percent of the forests in the Northeast had been cleared by the mid-nineteenth century.\textsuperscript{15} Land clearing on such a massive scale set other major ecosystem and biodiversity changes into play that are still prevalent today and from which full recovery or restoration may not be feasible.

\textbf{Chapter 2. What’s Lurking in Your Yard?}

\textit{What is Lyme disease?} Lyme disease is the most common vector-borne disease to affect humans in the United States, Europe, and Asia.\textsuperscript{16} The majority of the reported cases of Lyme in the United States are in the coastal Northeast, the Mid-Atlantic States, Wisconsin, Minnesota, and northern California.\textsuperscript{17} It is a zoonotic disease, meaning it can be transferred from animals to humans.\textsuperscript{18} The disease is caused by the \textit{B. burgdorferi} spirochete.\textsuperscript{19} Spirochetes are a type of bacteria that are long and wavy in appearance. Their length and shape enables them to move around and change directions.\textsuperscript{20} These spirochetes are transmitted to humans following the bite of an infected blacklegged tick (\textit{Ixodes scapularis}), also known as the deer tick.\textsuperscript{21} Ticks are

\begin{itemize}
\item \textsuperscript{16} Schauer, “Modeling,” 1.
\item \textsuperscript{17} U.S. Department of Health and Human Services. “Lyme Disease,” 8.
\item \textsuperscript{19} Schauer, “Modeling,” 1.
\item \textsuperscript{20} Barbour, \textit{Lyme Disease}, 3.
\item \textsuperscript{21} Schauer, “Modeling,” 1.
\end{itemize}
parasitic, blood-sucking arthropods that act as vectors, transmitting a number of diseases to both humans and animals. Early cases of Lyme disease are commonly diagnosed during the summer when densities of infected nymphs are highest. 

**The Discovery.** Lyme disease was first discovered in 1975 in Lyme, Connecticut following complaints of an unusually high number of diagnoses of children with juvenile rheumatoid arthritis. Rheumatoid arthritis is an uncommon disease in children, which is why its widespread occurrence in Lyme sparked a need for investigation. The disease was discovered in 1975, but it is believed to have been affecting people for decades prior to this finding. Doctors and scientists knew that this was a new disease, but they lacked a full understanding of its cause, the long-term effects it had on the body, as well as how to treat it. In 1981, doctors learned that Lyme disease was caused by the *B. burgdorferi* spirochete, which was transferred to humans following the bite of an infected blacklegged tick. Doctors also determined that Lyme disease could be successfully treated with antibiotics.

**Signs and Symptoms.** Erythema migrans, or the bull’s eye rash, is the most common indicating symptom of Lyme disease. This rash is typically the first sign of infection, and the only symptom that is unique to Lyme disease. Erythema migrans is caused by the spirochetes that are passed from the infected tick to the person’s skin. Following transmittance, the spirochetes move away from the initial bite area in all directions over a span of a few days or weeks. The rash can appear to grow in diameter as time goes on due to the movement of the bacteria. The spirochetes move between the person’s skin cells in search of blood and tissue.

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Their presence initiates an immune response in the host. Cytokines, signaling proteins, are released and trigger inflammation. The rash increases in size and the inflammation worsens as the spirochetes move farther across the skin. The rash appears pale in the center, and brighter red on the edge due to the location of the moving spirochetes. It can also develop red rings around the site of the bite. The rash received its nickname “bull’s eye” from this unique appearance (See Figure 2). Lyme disease can be difficult to diagnose because it causes a variety of other symptoms that can be confused with other diseases.

According to Barbour, early symptoms of Lyme include “fever, chills, muscle aches, headaches, and lethargy.” These symptoms are not unique to Lyme disease, which can make diagnosis difficult. More serious symptoms can arise if Lyme is not caught early enough. These serious symptoms begin when the spirochetes spread from the skin to the blood. Spirochetes can infiltrate blood vessels, veins, and arteries following entrance into the bloodstream. Afterwards, the spirochetes will enter the organs. It can take anywhere from weeks to years for neurological

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26 Barbour, Lyme Disease, 3-6.
symptoms of Lyme disease to appear.\textsuperscript{29} When Lyme disease spreads to the heart and nervous system, it can cause serious complications such as arthritis, facial paralysis (Bell’s palsy), and carditis.\textsuperscript{30}

Rheumatoid arthritis causes pain and swelling around the joints, and can make movement difficult. Arthritis has been observed in both children and adults who have been infected with\textit{B. burgdorferi}. The arthritis typically develops in the elbows and knees. It can become debilitating if the patient experiences chronic swelling, making manipulation and use of the joints extremely painful and difficult.\textsuperscript{31} Facial paralysis (Bell’s palsy) is caused by inflammation of the nerve that connects the brain to the facial muscles. This inflammation typically causes one or both sides of the face to droop. The patient can experience double vision and hearing difficulties if inflammation spreads to the nerves connecting the eyes and ears to the brain. Inflammation of the nerves is caused by a collection of water and white blood cells around the blood vessels. The blood vessels can eventually become blocked if the inflammation persists. The vessels cannot function correctly if they do not receive blood to provide nutrients and remove wastes. If the vessel remains blocked, then nerve cells can become damaged and even die.\textsuperscript{32} If spirochetes have infected the brain blood vessels, the patient may feel weakness on one side of the body, as well as experience speaking or understanding difficulties. Nerve cells can begin to die if the blood vessels in the brain are completely blocked. Thinking, speaking, and motor skills can be permanently impaired if enough nerve cells die.\textsuperscript{33} Lyme disease can also cause meningitis, which is caused by swelling and stretching of the lining of the brain.

\textsuperscript{29} Barbour, \textit{Lyme Disease}, 9-10.
\textsuperscript{30} Ostfeld, \textit{Lyme Disease: The Ecology}, 361.
\textsuperscript{31} Ostfeld, \textit{Lyme Disease: The Ecology}, 351.
\textsuperscript{32} Barbour, \textit{Lyme Disease}, 10-12.
\textsuperscript{33} Barbour, \textit{Lyme Disease}, 11-12.
leading to headaches and neck stiffness.\textsuperscript{34} Other symptoms can include shooting pains in the arms, legs, and trunk.\textsuperscript{35} Spirochetes initiate an inflammatory response upon entering the heart. An infection of the heart creates complications because the muscles within the heart become inflamed. This inflammation dangerously reduces the heart’s ability to pump blood by about half its normal rate. As a result, the heart will beat about thirty to forty times per minute, rather than sixty to eighty times.\textsuperscript{36}

\textit{Diagnosis and Treatment Methods}. Diagnosing Lyme disease is not always simple. There are high levels of uncertainty in diagnosis because patients can experience a wide variety of symptoms characteristic of other illnesses. A fairly certain diagnosis of Lyme disease would be if a patient comes to their physician during the summer after noticing the characteristic bull’s eye rash on their skin. The patient claims that they noticed that the rash formed in the area where they had recently been bitten by a tick. They state that the rash does not itch, but has increased in size, and they also have a low-grade fever and some mild muscle aches. The patient also reveals that they had spent a lot of time outdoors throughout the summer. Each of these factors combined make Lyme disease seem like the obvious culprit, so the physician will be able to make the diagnosis with a high amount of certainty. As a result, the patient will not need to receive any tests, but will be put on antibiotics as soon as possible.\textsuperscript{37} Some patients do not recall being bitten by a tick, or noticing a rash, and yet experience other symptoms that can be observed in people with Lyme disease. If a patient experiences symptoms that could indicate a variety of different illnesses, then tests will need to be performed to find out whether or not they have Lyme disease, or something else.

\textsuperscript{34} Barbour, \textit{Lyme Disease}, 11.  
\textsuperscript{35} Barbour, \textit{Lyme Disease}, 12.  
\textsuperscript{36} Barbour, \textit{Lyme Disease}, 14.  
\textsuperscript{37} Edlow, \textit{Bull’s Eye}, 160-161.
The main tests used to detect Lyme disease include the ELISA test, and the Western blot test (immunoblot). Both of these tests are used to detect the presence of antibodies in the bloodstream against the *B. burgdorferi* bacteria.\(^{38}\) These tests do not always produce the correct result as to whether the person has Lyme disease or not. The results may show up negative if the test is conducted in too short amount a time following a tick bite. The negative test results do not necessarily prove that the person does not have Lyme. It can take a person anywhere from few days to a few weeks to produce antibodies following infection by the spirochetes.\(^{39}\) The CDC has recommended that both Lyme tests be administered to patients in order to give a more accurate diagnosis. The ELISA is given first as a form of screening test, and the Western blot is given later to confirm whether or not the antibodies against *B. burgdorferi* are present.\(^{40}\)

Physicians prescribe either oral or intravenous antibiotics following a Lyme disease diagnosis. Patients may be instructed to take the antibiotics anywhere from a few days, to a few months depending on the severity of the infection.\(^{41}\) Physicians prescribe oral antibiotics if Lyme disease is detected early, or if the patient suffers from chronic Lyme disease that has not entered the heart or nervous system. The most commonly recommended oral antibiotics include amoxicillin and doxycycline. Other common antibiotics are cefuroxime, cefixime, azithromycin, clarithromycin, and minocycline. Physicians prescribe intravenous antibiotics if the infection has entered the heart, eye, or nervous system. Intravenous antibiotics may also be prescribed after a trial of oral antibiotics fails to stop the infection. Commonly prescribed intravenous antibiotics include cefotaxime, ceftriaxone, and penicillin. Physicians sometimes disagree on whether to prescribe oral or intravenous antibiotics when it comes to Bell’s palsy and arthritis.

\(^{40}\) Edlow, *Bull’s Eye*, 175.
\(^{41}\) Barbour, *Lyme Disease*, 151.
Many physicians will first perform a spinal tap to see if they can detect the presence of increased white blood cells or protein in the cerebrospinal fluid. High levels of white blood cells and protein indicates that that brain is infected with spirochetes. The physician will most likely prescribe intravenous antibiotics under these circumstances. If there are no abnormalities in the cerebrospinal fluid, then the brain is most likely not infected, and the physician will prescribe oral antibiotics. Historical land-use practices have altered forest ecosystems and contributed to the current prevalence of Lyme disease in North America.

Chapter 3: A Trail of Breadcrumbs

The Native Americans and colonists that once occupied the northeastern portion of the United States created drastic changes in the forest ecosystems that have contributed to the rise of Lyme disease today.

Native American Beliefs. Native Americans believed in interacting with the land through reciprocity. They believed that they could maintain a mutually beneficial relationship with the environment, as long as they treated the land and its resources with respect. The land provided the Native Americans with food, water, fuel, and other resources. In return, they would provide the land with nutrients and other offerings. The used the land in a sustainable way. The Native Americans also believed that all of the animals housed the spirits of their ancestors, and served as guardians on earth. This belief caused Native Americans to develop a great respect for the land and for the animals that they shared it with, especially the animals that they hunted. Native Americans would never kill more animals than they needed. They believed that their ancestors would become angered and punish them if they neglected to show respect to the animals that

42 Barbour, Lyme Disease, 152-153.
they hunted. Although Native Americans believed in reciprocity and sustainability, they were responsible for many changes in the land that have shaped the northeastern landscape that exists today.

**Native American Land-Use Practices.** The use of fire was the Native Americans’ most widespread and effective land-clearing technique. Fire was mainly used to clear land for agriculture, as well as to improve hunting conditions in the forests. Fires were typically lit twice a year. The fires burned quickly and low to the ground because there was an abundance of smaller plants to burn on the forest floor. Fires rarely reached the canopy, and they often burned out on their own. The landscape was described as being park-like following a burn because the forest floor was clear of brush, creating wider paths between the trees. Traveling was quicker and easier with a cleared forest floor. Hunting improved because the hunters and prey could move through the forest with greater ease. There was also less brush present to interfere with a hunters’ gaze while spotting game. Burning also promoted the growth of many of the plant species that game animals, such as white-tailed deer, preferred to eat. This increased availability of food sources led to rise in white-tailed deer populations, and an eventual growth in their predator populations. The ash created by the fire also fertilized the soil, and provided it with nutrients. This resulted in an increase in abundance of grasses, shrubs, and other plants on the forest floor. The fires would open up the canopy by burning down the smaller trees. This allowed more sunlight to shine through to the forest floor, and further contribute to the increase in the plant growth rate. Native Americans also used fire to clear land for agriculture.

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Native Americans were both hunter-gatherers, and sedentary people who cleared land for agriculture. There were approximately 287 Native Americans per hundred square miles in New England before the arrival of Europeans. By 1600, their total population reached numbers between 70,000 and 100,000. Native Americans would use fire to girdle trees while clearing land for agricultural purposes. With this technique, Native Americans would light fires at the bases of trees so that the bark would burn off. The trees would die slowly following this severe bark damage. They would gradually release nutrients into the ground as they continued to decay. The Native Americans would plant crops on these newly cleared lands. A single agricultural field required the clearing of up to several hundred acres of forest. Native Americans primarily planted maize, beans, and squash in their fields. They typically could rotate these crops on a piece of land for a ten to twenty yearlong fallow cycle. They were able to farm on the same area of land for extended periods of time because they planted beans, which aided in maintaining nutrient levels in the soil. Beans helped to reduce the loss of nitrogen in the soil. Over time, the soil became exhausted of nutrients, and the Native Americans would need to move to a new piece of land. By this time, not only had the nutrients in the soil been extremely depleted, but many of the resources of the land had also been exhausted. Native American villages in Connecticut alone could clear up to 2,300 acres of land for agriculture in just fifty years.

Native Americans began to engage in trade with European colonists during the sixteenth century. Interactions with the Europeans led to a decline in the Native American traditional practices, over-exploitation of the land and its resources, as well as radical reductions in native populations. Native Americans would trade animal pelts in exchange for European goods such

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46 Cronon, *Changes*, 41-41.  
as muskets, steel tools, horses, and other items. The fur trade began to place a price on resources from the land. As Native American demand for European goods increased, so did their overuse of natural resources. The desire for goods led the Native Americans to compromise their traditional belief system, and strip the land of its resources. They adapted their old belief of reciprocity, and by necessity, began to take more than what they needed. By over-exploiting natural resources, the Native Americans took too much from the environment too quickly, and the land suffered as a result.\textsuperscript{51} The Native Americans over-hunted white-tailed deer and beaver because their pelts where highly coveted on the European market. The trade of white-tail pelts began in the sixteenth century. More Native Americans began to acquire muskets from trading with the Europeans. The use of firearms made hunting of white-tailed deer, and other animals, quicker and easier. Before the fur-trade, Native American families would kill anywhere between twenty five to one hundred deer each year, depending on what the families needed. After the fur-trade began, families were killing anywhere from two hundred to four hundred white-tailed deer per year.\textsuperscript{52} By the seventeenth century, approximately 85,000 deerskins were traded per year. Over 500,000 were traded per year in the eighteenth century, and about 100,000 per year by the nineteenth century until the trade eventually ceased.\textsuperscript{53} The trade eventually ended because animal populations had reached dangerous lows, and many Native Americans had been killed by infectious diseases.

New England Native American populations dropped from 70,000 to 12,000 in the seventeenth century. They were killed off so rapidly from their exposure to European diseases during trade. Native Americans lacked immunities to these foreign infectious diseases. They died from a variety of epidemics including tuberculosis, pneumonia, influenza, measles, typhus,

\textsuperscript{51} Judd, \textit{Second Nature}, 56.
\textsuperscript{52} Kretch III, \textit{The Ecological Indian}, 158.
\textsuperscript{53} Kretch III, \textit{The Ecological Indian}, 160.
dysentery, syphilis, and other diseases.⁵⁴ The Native Americans continued to engage in trade despite the thousands of deaths that occurred in the seventeenth century. They had witnessed what their exploitative actions had done to their lands, resources, and ancestors, and yet they still participated in trade. It is believed that the Native Americans at this time did not have many other options besides to continue engage in trade. According to Judd, “The loss of nearly an entire generation wiped out the memory of hunting skills, crafts, and culture, and the lack of these traditional practices deepened the natives’ dependence on European goods even as the outbreaks heightened their fear of the English.”⁵⁵ Their lands’ resources had been used up, and they were dependent on Europeans to obtain the goods that they needed to survive. As Native American populations continued to decline, Europeans began to take over the abandoned land, and exploit it even further.

**European Land-Use Practices.** The first Europeans to colonize the Northeast were the English in the Gulf of Maine, the French on the Penobscot River and Bay of Fundy, and the Pilgrims who arrived in Plymouth, Massachusetts in 1620.⁵⁶ Unlike the Native Americans, Europeans viewed the land and its resources as commodities. They had no interest in only taking what they needed from the environment like the Native Americans. Rather, they just saw the resources in the environment as inexhaustible and took as much as they could for profit. Colonists were especially interested in white pine, which they would use to build ships. Other tree species were utilized for constructing houses, fences, and other structures.⁵⁷ Trees and

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animal furs were highly coveted and treated as commodities that the colonists would send back to Europe for a profit.\textsuperscript{58}

The Europeans adopted the Native Americans’ land-use techniques, but neglected to practice them in a sustainable way. Unlike Native Americans who would use fire to clear the understory, colonists used fire to completely burn the forests down and clear the land. They also adopted the tree girdling technique. They would manually strip the bark off of the bases of trees, which would lead to their eventual death. The trees would slowly release nutrients into the soil over time as they rotted. This allowed the land to stay fertile for farming for longer periods of time. After the trees died and fell to the ground, more light could reach the understory, allowing the colonists to plant crops on the land.\textsuperscript{59} Colonists also practiced a “slash and burn” land-clearing technique. They would chop the trees down and let them lay on the forest floor for a year. Then in the spring, they would burn the decaying fallen trees. The ash from the burned trees served as a fertilizer for the soil. The ground was ready to be planted with crops following the burning. This technique was the least sustainable land-clearing technique, because the soil remained fertile for about a year, and would rapidly decline in quality soon after that. As a result, the “slash and burn” technique created a greater immediate benefit in terms of crop output within the first year, but lead to rapid soil exhaustion.\textsuperscript{60}

Colonists differed from Native Americans in terms of their agricultural practices because the colonists had domesticated animals. Some of the animals were used for farming purposes. For example, oxen were used to pull the plows in the fields. The Europeans also had cattle, pigs, horses, and sheep. The domesticated animals were fairly hardy, and so the colonists allowed them to roam freely in the forests during the warmer months so that they could be recaptured and

\textsuperscript{58} Cronon, \textit{Changes}, 109.
\textsuperscript{59} Cronon, \textit{Changes}, 116.
\textsuperscript{60} Cronon, \textit{Changes}, 118.
killed in the fall. The animals would graze on native vegetation as they traveled through the forest. The free roaming and grazing domesticated animals contributed to the development of weed plants in northeastern United States. Weeds evolved from regular native plants. The native plants began to develop adaptations that helped to prevent them from being eaten, which eventually led to the evolution of weeds. Common characteristics of weeds included the ability to grow and develop rapidly and under a wide variety of environmental conditions. They also produced large quantities of seeds to increase their chances of spreading and growing in other locations. Finally, the weeds were brittle so that they were more effective at growing back following being broken by a browsing domesticated animal. Constant burning and the introduction of domesticated animals led to a change in the plants found in the forest understory. Grazing animals increased the spread and the growth of woody and spiny plants because they were unpalatable. The domesticated animals were eating the other native plant species that would normally compete with the unpalatable plants for resources. With a reduction in competing species, woody and spiny plants and shrubs were able to spread more rapidly. There were so many domesticated animals concentrated in small areas of land that their weight would compact the soil to the point where it would dry out, impacting the ability of oxygen to reach root systems. This decrease in oxygen lowered plants’ abilities to absorb water and nutrients, and caused toxic chemicals to begin to collect in the soil. The soil’s ability to hold water was also reduced. These negative impacts on soils led to erosion and a loss of fertile topsoil. Collectively, these degraded soil conditions made it difficult for any species of vegetation to grow, especially native species.

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61 Cronon, Changes, 128-129.
62 Cronon, Changes, 143.
63 Cronon, Changes, 144.
64 Cronon, Changes, 146.
The domesticated animals would feed on all of the edible plants fairly early in the season. As a result, the colonists would have to move them to new areas of land, where they would create the same ecological impact. The use of animals also allowed farmers to clear large fields for agriculture, compared to the Native Americans who would use hoes to clear smaller patches of land by hand. Plowing had a major negative impact on the environment such as increased erosion of topsoil and the subsequent loss of important soil nutrients. Farmers would use animals, usually oxen, to pull the plows through the soil, in order to remove all native plant species, to make room for domesticated crops.65 The colonists engaged in both agriculture, and trade of a variety of goods.

The fur trade began in New England in the 1500s, and had become a significant contributor to the colonial economy by the 1600s. According to Judd, “Operating out of Boston or England, merchants hired settlers to clear fields, build sawmills, cut marsh hay, and split white oak into pipe staves and ships’ timbers; by midcentury, fur-trading companies were overseeing a diversified frontier economy that exported furs, lumber, grains, meal, flour, fish, livestock, and small ships.”66 As stated earlier, the fur trade led to overexploitation of animals, such as the white-tailed deer. Reductions in animal populations led to further drastic repercussions in the New England forest ecosystems.

With the decline of the white-tailed deer, moose, pigeon, and turkey populations by the 1800s, their natural predators began to turn to alternative forms of prey.67 Wolves were native predators to New England at the time. As their natural prey vanished, wolves began to turn to the colonists’ domesticated animals as an alternative and abundant food supply. The predators’ wandering eyes sparked anger and revenge in the colonists affected. In response, colonists

65 Cronon, Changes, 146-147.
67 Judd, Second Nature, 94.
Russo

would often offer up a bounty as reward for anyone who killed the wolf that was plaguing their livestock. As wolves, bounties were also offered up for “wildcats, bears, cougars, lynx, foxes, blackbirds, jays, woodpeckers, crows, owls, [and] hawks.” As observed in the fur trade with the Native Americans, the predators began to be viewed and treated as commodities. By creating bounties, the colonists were placing a price on the animals. Many people wanted to collect the bounties for themselves, and would purposely kill the wrong animals and claim that they were the ones with the bounties on their heads. Bounties created an incentive for colonists to kill large numbers of animals over short periods of time.

As colonists continued to overexploit the land, the land became depleted of the resources that the settlers needed to subsist, so they began to look to the West. According to Cronon, “deforestation, grazing, plowing, erosion, and watershed changes all contributed to a problem that became endemic to colonial agriculture in New England: soil exhaustion.” Deforestation accelerated soil erosion and surface runoff. Vital minerals and nutrients in the soil would be washed away along with it. This made it difficult for new vegetation to grow back. Grazing of domesticated animals encouraged the growth of weeds that would compete with native plant species. Livestock also compacted the soil under their weight, causing it to dry out and erode, reducing the soil’s ability to hold water. Once the soil was exhausted, the colonists could no longer use it for agricultural purposes. By the 1800s, some colonists began to abandon their land and move west. Westward movement increased after the Civil War. Farm abandonment was not solely caused by soil exhaustion. It was also encouraged by urban growth, federal land distribution in the West, the California gold rush, the drop in grain prices, the opening of new

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68 Cronon, Changes, 132.
69 Judd, Second Nature, 94.
70 Cronon, Changes, 132.
71 Cronon, Changes, 149-150.
farmlands in the United States, Canada, and Australia, as well as the Chicago meatpacking industry. 

Reforestation and Repopulation. Widespread reforestation took place following the colonists’ abandonment of the Northeast. “By 1860, all but 27 percent of the entire area of Connecticut was open land. Those were the peak years. By 1910, the woods had expanded to cover 45%; and by 1965, 63% of the state.” Today approximately three-quarters of New England is covered by forest.

Repopulation of the Northeast was slow during the twentieth century, allowing more time for reforestation. It was not until the time period between the 1950s to the 1970s, did people begin to rapidly repopulate the Northeast. This migration began after World War II. The Northeast, along with the Great Plains contained approximately 84% of America’s population by 1950. Populations in rural areas were growing more rapidly than in metropolitan areas. By the 1970s, people were migrating out of the cities and into the suburbs. Over time, human repopulation of the reforested areas in the Northeast placed humans in closer contact with Lyme disease carrying ticks.

By the twentieth century, states began to create conservation programs, and pass game laws in the hopes of protecting the remaining animal populations that had been decimated due to the fur trade and bounties. Many conservation programs worked on the reestablishment of

74 Ginsberg, Ecology, 1047.
77 Brown,“Rural,” 5-8.
white-tailed deer herds.\textsuperscript{78} Restocking programs for white-tailed deer were created in the 1930s and 1940s.\textsuperscript{79} They were able to thrive in the areas where the forest had regenerated because they lacked the natural predators that they once had. As a result, deer populations increased exponentially.\textsuperscript{80} Their populations grew from being in the tens of thousands in the 1920s, to 300,000 by 1950, and approximately 2.5 million by 1970. Today there are over 25 million white-tailed deer found in North America.\textsuperscript{81}

Chapter 4: Ecosystems Out of Balance

Impact of Biodiversity on Ecosystem Services. Biodiversity measures the species richness of an ecosystem. An ecosystem with high levels of biodiversity has a variety of different species of flora and fauna. A healthy ecosystem is one that is balanced and naturally sustaining with high amounts of biodiversity. An ecosystem with low levels of biodiversity has a limited number of different species of animals. Ecosystems with low biodiversity levels are considered unhealthy and out of balance. The historical land-use practices employed by the Native Americans and the colonists in the Northeast caused a decrease in biodiversity and ecosystem services. This change in the land has led to increased tick populations and cases of Lyme disease today.\textsuperscript{82}

According to Wilson, ecosystem services are “the role played by ecosystems in creating a healthful environment for human beings, from production of oxygen to soil genesis and water detoxification.”\textsuperscript{83} An ecosystem with high levels of biodiversity is healthy and balanced, and

\textsuperscript{78} Judd, Second Nature, 268.
\textsuperscript{79} Kretch III, The Ecological Indian, 171.
\textsuperscript{80} Judd, Second Nature, 268.
\textsuperscript{81} Kretch III, The Ecological Indian, 171.
\textsuperscript{82} National Wildlife Federation. “What is Biodiversity.” nwf.org.
able provide its ecosystem services in full capacity. One important ecosystem service is the control of infectious diseases. The control of infectious disease is heavily dependent on biodiversity level. Every species that gets added to an ecosystem increases the efficacy of the ecosystem services. Every species that is lost decreases the efficacy of the ecosystem services. Thus, biodiversity loss leads to an increase in the spread of infectious disease. The biodiversity in the forest ecosystems of the Northeast have been severely reduced due to the aggressive land-use practices that took place as colonists increasingly spread throughout the Northeast. Deforestation, habitat fragmentation, overhunting, soil exhaustion, livestock, reforestation, repopulation of white-tailed deer, and the introduction of invasive species all contributed to the decline in native species of flora and fauna. They have also allowed for an increase in tick breeding sites, and the availability of hosts that exist today. This loss of biodiversity and ecosystem services has led to a reduction in control of infectious disease. This has allowed tick populations and Lyme disease to rise to the epidemic levels at which they exist today.

As discussed in Chapter III, both Native Americans and colonists cleared vast areas of land for a number of reasons. Clearing of the land allowed for the removal of native species of plants over vast areas, which contributed to habitat and biodiversity loss. Native Americans would burn the understory to make travel and hunting easier, as well as to provide more suitable habitat for white-tailed deer. This strategy altered both plant and animal biodiversity. Deer populations increased because the fire enabled more of their food sources to become available. As a result, the deer would browse on their desired food sources, while leaving other unpalatable plants alone. These food preferences of white-tailed deer allowed for an increase in the growth of spiny, woody shrubs. This same result occurred after the colonists allowed their livestock to

roam free in the forest. Browsing livestock also encouraged the evolution of weeds. As a result, unpalatable plants and weeds were left alone by browsing animals, as other native species were being over-grazed. Deer and livestock enabled the unpalatable weeds and shrubs to outnumber and outcompete the other native plant species, therefore reducing plant biodiversity. This lowered the plant biodiversity because it created an imbalance in the species populations.\textsuperscript{86}

Clearing of the land also contributed to habitat fragmentation.

Clearing vast areas of land caused widespread habitat fragmentation in the Northeast. Habitat fragmentation occurs when a habitat is subdivided into smaller pieces. This causes a loss of the original habitat, reduction in habitat size, and isolation of the smaller habitat pieces. This displaces animals and reduces their range. Habitat fragmentation also causes a reduction in biodiversity because less habitat and resources are available for the organisms to use to subsist. As a result, it negatively impacts plant and animal populations.\textsuperscript{87} Habitat fragmentation is believed to have contributed to the high populations of white-footed mice that are present in the Northeast today. White-footed mice are significant tick hosts, which contribute to the spread of Lyme disease. The mice populations seem to increase with habitat fragmentation because they have fewer predators and competing species within smaller fragmented habitats.\textsuperscript{88}

Trade also contributed to the reduction of plant and animal biodiversity in the Northeast. This led the colonists to over-harvest white pines in order to use them for ship construction.\textsuperscript{89} The depletion of one species contributes to a reduction in biodiversity. The fur trade greatly reduced animal populations to the near brink of extinction. Overhunting of white-tailed deer

\textsuperscript{86} Cronon, \textit{Changes}, 146-147.
\textsuperscript{88} Saundry, “Ecosystems.”
\textsuperscript{89} Cronon, \textit{Changes}, 30.
populations and their apex predators, such as wolves, reduced biodiversity.\textsuperscript{90} Even after white-tailed deer were reintroduced to the Northeast and their populations increased exponentially, the biodiversity is still poor, because the deer lack natural predators. So, white-tailed deer populations are able to continue to increase without any sort of population control.\textsuperscript{91} High deer populations supply more hosts for ticks to feed on. This causes an increase in tick populations, as well as cases of Lyme disease.

\textit{Case Study.} Many invasive species found in the Northeast today came from the temperate zones of Europe and Asia. These invasive flora and fauna are able to thrive in the northeastern United States, because the forests experience similar climates to those in Europe and Asia. One significant reason that invasive species are able to dominate ecosystems is because they lack natural predators. In addition, invasive species are often opportunistic, adaptable to less than ideal conditions, able to reproduce rapidly, and thus out-compete native species for resources. As a result, once invasive species begin to dominate an ecosystem, they reduce biodiversity to the detriment of native species. One invasive plant species, Japanese barberry (\textit{Berberis thunbergii}) is widespread across the eastern United States.\textsuperscript{92}

Japanese barberry originates from central and southern Japan and was brought to the United States in 1875 where it was marketed as a decorative plant. Today, it is widespread across forest understories all over the eastern United States.\textsuperscript{93} It has become naturalized in at least thirty-two states in the United States.\textsuperscript{94} Barberry is a dense spiny, perennial shrub with a

\begin{footnotes}
\footnote{90}{Cronon, \textit{Changes}, 132.}
\footnote{91}{Kretch III, \textit{The Ecological Indian}, 171.}
\footnote{92}{DeGasperis, “Windows,” 2.}
\footnote{93}{DeGasperis, “Windows,” 2.}
\end{footnotes}
woody stem (See Figure 3). It forms dense thickets, making it difficult for native plants to compete, and for reforestation to occur. It is very tolerant of different light and soil conditions. Deer do not feed on the barberry, and are therefore enabling its spread. This is because the deer are eating all of the native vegetation, and are therefore reducing competition for resources for the barberry. Barberry is found on areas of land that were once cleared for agriculture, and then became reforested. It is especially common in the Northeast because many of the forests were cleared for agriculture back when Native Americans and colonists inhabited the land. It is theorized that Japanese barberry is associated with elevated levels of blacklegged ticks, the carriers of the Lyme causing *B. burgdorferi* spirochete. It is also believed that Japanese barberry provides ideal habitat for blacklegged ticks. Since it is a shrub, it provides a degree of shade that creates ideal temperature and moisture levels for ticks. As a result, Japanese barberry may be contributing to a major public health threat.

![Figure 3: Japanese barberry plant](image)

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100 Williams, “Effects of Japanese Barberry,” 2.
This theory was tested at Fordham University’s Louis Calder Center in Armonk, New York. The forest within the Louis Calder Center has Japanese barberry located all throughout the understory. Calder is also home to many white-tailed deer. Barberry, along with other invasive plant species are common in the otherwise cleared understory. In this study, we sought to establish whether plant biodiversity influenced blacklegged tick densities. We believed that plots with lower levels of plant biodiversity would result in higher tick densities. To test this hypothesis, we used a transect and quadrat sampling method to record the plant biodiversity of four 2,500 square meter forest plots. We then collected ticks in each of the plots over a three-day period. After analyzing the data, we observed that we collected more ticks in the plots with lower plant biodiversity (See Appendix, Figures 5 and 6). The plots with lower biodiversity also had higher concentrations of Japanese barberry. These results, albeit preliminary, could mean that Japanese barberry is out-competing the native plant species, with the help of browsing deer. The presence of barberry is decreasing biodiversity and providing more habitat for blacklegged ticks. These preliminary study results indicate that there could be a strong correlation between the presence and high density of Japanese barberry and blacklegged ticks. If this is true, then barberry could be contributing to the spread of Lyme disease in the Northeast.

*Life Cycle.* Ticks have a two yearlong life cycle, within which they must feed three times in order to be able to go through metamorphosis and reproduce (See Figure 4). Ticks are not born with the spirochete that causes Lyme disease, but contract it by feeding on an infected host. When tick larvae are born in late summer, they emerge from the ground and remain in the leaf litter until they find their first blood meal. Tick larvae primarily feed on small mammals, birds and reptiles that are frequently close to the ground. White-footed mice are the most competent and most abundant *B. burgdorferi* reservoir. In other words, they have the highest ability to
transmit the Lyme disease causing spirochete to the ticks.\textsuperscript{103} After feeding, the larvae will drop off the host, and burrow under the ground. They will not emerge until the following spring after they have developed into nymphs. The infected nymphs emerge from the ground towards the end of spring in search of a meal. They stay close to the leaf litter like the larvae. They are out until about mid-August. Humans will most likely contract Lyme disease from a nymph, because nymphs will primarily feed on small mammals, birds, reptiles, and humans. Like the larvae, nymphs can also receive the \textit{B. burgdorferi} spirochetes from feeding on an infected host. The nymphs burrow back under the ground at the end of the summer, and emerge again in the fall as adults. The adults mainly quest for deer, because they must feed and mate on the deer before they drop off to lay their eggs.\textsuperscript{104} It is for this reason that humans are less likely to contract Lyme disease from an adult tick. Also, if an uninfected tick fed on an infected deer, the deer may not transmit the spirochetes to the tick. This is because the deer are not competent reservoirs for \textit{B. burgdorferi} bacteria. In other words, deer are not effective at transmitting Lyme disease. White-footed mice, and chipmunks on the other hand, have the highest reservoir competence for the spirochetes. These two species of rodent are also highly abundant in the Northeast. So, populations of white-footed mice, and chipmunks are also contributing to the spread of Lyme disease. Infected mice and chipmunks transmit the spirochetes to larvae and nymphs, who in turn spread the disease to uninfected hosts.\textsuperscript{105}

\textsuperscript{103} Schaubur, “Modeling,” 2.
\textsuperscript{104} Khatchikian et al., “Geographical,” 3.
\textsuperscript{105} Schmidt, “Biodiversity.”
The high numbers of white-footed mice, chipmunks, and white-tailed deer reduces the “dilution effect,” among the host species for the tick. In other words, the wider the variety of host species there are available for ticks to feed on, the lower the risk of human exposure to Lyme disease. This is because if the ticks are exposed to a variety of hosts, the majority of which are incompetent reservoirs, then they will be less likely to feed on an infected, competent host that will transmit spirochetes to them. As a result, the chance of spreading Lyme disease to humans is reduced. The “dilution effect” is most effective with high levels of biodiversity. As we have seen from the historical land-use practices, the biodiversity in the Northeast is low.\(^{107}\)

**Climate Change.** Climate change is contributing to the spread of Lyme disease. Climate change is increasing the number of warmer months per year. This allows the ticks, and their hosts, to emerge earlier, and feed later in the year. This increases their chances of feeding, reproducing, and spreading Lyme disease. Climate change can lead to an increase in tick populations because it increases temperatures at all latitudes. As a result, it is increasing the


geographic range of many species of animals. So as temperatures increase, animals are able to expand their distribution farther north and south. This could allow for the same geographic spread of tick hosts, tick populations, and Lyme disease. It has been recorded that populations of white-footed mice and blacklegged ticks have been expanding their ranges northward over the last few decades due to mild winters and warmer temperatures. If the winters are mild and the temperatures are altogether warmer than normal, then the snow will melt earlier in the season. This will lead to more mouse activity and breeding earlier in the year, allowing them to come into contact with infected ticks earlier in the year.\textsuperscript{108}

\textbf{Chapter 5: Intercepting Lyme disease}

The changes that have occurred in the ecosystems in the northeastern temperate forests over the past few centuries cannot be reversed. It is important to use the rise of Lyme disease as an example of how environmental disturbances can produce negative impacts on ecosystems and human populations in the future. It is vital that the public recognizes this relationship and begins to be more conscious of their actions within the environment. The best way to slow the spread of Lyme disease is to inform people about a number of mitigation and adaptation solutions. These solutions will provide the public with strategies to reduce tick numbers around their homes, as well as employ a number of defensive practices that will decrease their chances of being bitten by infected ticks. Widespread use of these policies will decrease tick populations, and slow the spread of Lyme disease in North America.

\textit{Mitigation Policies:}

\textsuperscript{108} Julie A. Simon et al. “Climate Change and Habitat Fragmentation Drive the Occurrence of \textit{Borrelia burgdorferi}, the Agent of Lyme disease, at the Northeastern Limit of its Distribution.” \textit{Evolutionary Applications} 7 (2014): 750-751.
**Land Management.** People can reduce the numbers of ticks on their properties by applying acaricides to their lawns. Acaricides are pesticides specifically designed to kill ticks and mites. Acaricides, such as carbaryl and chlorpyrifos, are easily purchased at a local garden supply store. These pesticides inhibit nerve and muscle function in the ticks and mites. They can be added to the lawn in late May to kill the emerging nymphs, and in early September to kill the emerging adults. For best results, the homeowner should spread the pesticides over the entire lawn, including the edges, as well as by ornamental plants, and on any parts of the lawn that share a border with forest. This technique should reduce the number of ticks by 95 percent.

Since pesticides can have negative impacts on public health due to long-term exposure, and some pesticides can leech into groundwater, people are beginning to try to control ticks with chemicals that are less toxic. Some soaps and salts of fatty acids are effective at controlling tick populations. The soaps dry out the ticks’ exoskeletons, causing them to dehydrate rapidly. The soaps are better for the environment because they degrade faster than other chemicals. Although the soaps seem to be a promising alternative, further studies are still required to determine their true efficacy in controlling tick populations.  

Another simple way to reduce tick populations is to decrease their ideal habitat near the home. There will be fewer numbers of ticks in the grass on a lawn. Lawns are not ideal habitat for ticks because they usually receive a lot of sun, making them drier and warmer. Shrubs, weeds, and leaf litter provide more cover and moisture that creates a favorable habitat for the ticks. Removing this vegetation will reduce tick populations around the house.

It is not wise to feed wild animals near the house because the food attracts tick hosts including white-tailed deer, and white-footed mice. Setting up bird feeders will attract birds and

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mice, the hosts of Lyme disease carrying nymphs. It is also important to make sure that pet food is not left outside either, because this will also attract potential infected tick carriers. Deterring tick hosts, especially deer, from entering the property is also important. Putting up a fence will stop deer from entering your property, and therefore decrease tick numbers around the house.  

*Animal Population Management.* Promoting hunting of white tailed deer would be helpful in reducing the spread of Lyme disease. Decreasing the deer populations will diminish the number of vector breeding sites for the ticks, which will reduce their opportunities to breed during their two-year life cycle. This reduction in host numbers will potentially lead to a decline in tick populations. Diminishing the deer populations will also decrease the number of ticks that get carried into people’s backyards by wandering deer.

*Invasive Plant Management.* If invasive plant species cannot be eradicated, then they must at least be controlled. By controlling the invasive plant species populations, people would be allowing native plant species begin to grow back to a level where they are able to compete with the invasive species. Different control methods may be required for different species. For the invasive Japanese barberry, the most effective method would be to burn the barberry. If this technique is not possible, then another effective method would be to physically cut down or remove the barberry, and then apply herbicide to the stumps. Each of these control methods must be continued over time so as to keep the barberry populations under control. This will give native plants the chance to regenerate, therefore increasing plant biodiversity, and decreasing the habitat available to Lyme disease carrying ticks.

*Biocontrol.* In terms of biocontrol, a tick predator or parasite could be introduced in order to decrease the tick populations. There is a species of parasitic wasp that lays its eggs inside of a

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112 Schaubер, "Modeling," 16
living tick. The tick is killed once the larvae hatch and begin to grow. This could be an affective biocontrol method. This type of wasp was released in 1930 in Massachusetts to control dog tick populations. There are other parasitic wasp species that exist that have yet to be tested in North America.\textsuperscript{114}

Another form of biocontrol that can be used to manage tick populations would be the application of fungi that grow on the forest floor. Two species, \textit{Metarhizium anisopliae} and \textit{Beauveria bassiana} kill ticks that are exposed to them. They interfere with the ticks’ feeding abilities, and prevent them from feeding as much as they could. As a result, the ticks may not be successful at molting to the next stage in the life cycle, or be able to lay eggs. These species of fungi can be found in pesticides for household pests such as termites and carpenter ants. It is possible that specific genetic strains of these fungi are especially effective at killing ticks.\textsuperscript{115}

\textit{Adaptation Policies:}

\textit{Clothing.} It is important to educate the public on the dangers of Lyme disease, as well as inform them about some preventative methods. The most effective method is to avoid living in and visiting places where Lyme disease is a common threat. Although this is the most effective method, it is also the most difficult for people because it would require an entire lifestyle change. Most people will choose to risk the disease over staying out of tick habitat, which is why there are a number of other preventative methods that people can practice.

Some simple preventative methods include wearing long sleeves and pants. Pant legs should be tucked into the socks and secured with masking tape. This method keeps the ticks on the outside of clothing, and decreases their chances of coming into contact with the skin, feeding, and transmitting Lyme disease. People should check their clothing regularly while passing

\textsuperscript{114} Barbour, \textit{Lyme Disease}, 234.
\textsuperscript{115} Ostfeld, \textit{Lyme Disease: The Ecology}, 3030, 3040.
through wooded areas. Wearing light colors is beneficial because it makes it easier to spot the dark ticks if they are crawling on clothing. Checking your skin and hair for ticks after spending time in tick habitat is one of the most important preventative methods. Adults should check their children and pets for ticks as well. The sooner a tick is found on the body, the lower the chances the individual has of contracting Lyme disease.\textsuperscript{116}

\textbf{Tick Removal.} It takes approximately twenty-four to thirty-six hours after the tick becomes embedded for the spirochetes to be passed from vector to host. If a tick is found attached to the skin, it should be removed as soon as possible. Ticks are extracted most effectively using curved forceps or tweezers. The ticks must be grasped by the head, and carefully pulled away from the skin. Removal techniques using a match, petroleum jelly, or nail polish remover are not recommended because they require more time to detach the tick from the skin. These methods waste time within which the spirochetes can be transferred from vector to host. The bite area should be cleaned with soap and water or antiseptic following tick removal. Saving the tick following removal is not entirely necessary, although identifying the tick species is beneficial in determining whether Lyme or other diseases could be contracted. The tick bite should be observed in the following days and weeks. The person should seek immediate attention from their physician if they notice the bull’s-eye rash around the bite area, or if they begin to experience other symptoms.\textsuperscript{117}

\textbf{Insect Repellents.} Using insect repellant containing DEET on the body deters ticks from latching on and feeding. DEET can be applied to the skin in concentrations ranging from 5 to 100 percent. The repellent stays potent anywhere between four and twelve hours. Permethrin is another popular insect repellant that can be applied to clothing, but not to skin. It kills ticks, as

\textsuperscript{116} Barbour, \textit{Lyme Disease}, 218-221.
\textsuperscript{117} Barbour, \textit{Lyme Disease}, 221.
well as other biting insects. Applying DEET to the skin, and permethrin to clothes creates an effective defense against ticks. Applying pesticides to lawns is another effective preventative method.\(^{118}\)

**Lyme Vaccine.** A Lyme disease vaccine was created in the late 1990s. This vaccine was unique, because instead of helping to boost the patient’s immunity against the *B. burgdorferi* bacteria, the antibodies were absorbed into the bodies of ticks that bit them, killing all of the spirochetes. The vaccine was manufactured and distributed in trials, but it ended up causing serious side effects in the people who received it. People complained of joint and muscle pains, as well as neurological problems. They were healthy upon receiving the vaccine, and then developed the side effects afterwards. There was a debate about whether the vaccine should be put on the market, but it ended up failing. There is no approved Lyme vaccine that exists today for humans, but there is one for dogs.\(^{119}\)

Researchers have tried to develop acaricides that could be applied to the skin white-footed mice and deer that would kill all of the ticks feeding on the animals at that time. A product was created called Damminix, which was designed to kill the ticks feeding on mice. When the product was being tested, people spread paper tubes filled with permethrin-impregnated cotton on their properties. The mice would take the cotton to build their nests, and the ticks would therefore be killed as the mice rested in their nests. This product displayed varied success in different locations. In terms of deer, people are looking to develop baited stations to attract deer to that they can be sprayed with an acaricide in some way. People are also studying the efficacy of ivermectin, a heartworm medication for dogs that also affects ticks. If a station provided bait for deer that contained ivermectin, then the ticks attached to the deer would

\(^{118}\) Barbour, *Lyme Disease*, 221-229.
be killed once the deer ate the bait. These theories still need to be tested. The difficulty with these approaches is controlling the dosage of pesticides or medication that each animal gets, as well as making sure that the stations do not attract the wrong species of animal. Setting up enough stations to have any sort of drastic impact will also be a challenge.¹²⁰

Historical land-use practices dating back to the sixteenth century altered the ecosystems within the temperate forests of the northeastern United States. These changes depleted the land of its resources and reduced biodiversity levels and the efficacy of ecosystem services. These environmental impacts occurred centuries ago, and yet are contributing to the high tick populations and spread of Lyme disease that is occurring today. Informing the public on the threat of Lyme disease, as well as strategies to avoid coming into contact with ticks is crucial in decreasing the spread of infection. Mitigation strategies such as land management, animal population management, invasive plant population management, and biocontrol will cause a decrease in tick populations, and therefore reduce the spread of Lyme. Adaptative strategies such as wearing appropriate clothing, tick removal, the use of insect repellants, and Lyme vaccines will decrease people’s chances of coming into contact with, and being bitten by infected ticks, and therefore reduce the spread of Lyme disease in the Northeast.

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Appendix: Calder Center Case Study Results

In June 2014, we set up four 2,500-m² sites containing Japanese barberry in different areas in the forest at Fordham University’s Louis Calder Center. We used the transect and quadrat sampling method to record the plant biodiversity within each plot. We identified each plant species within a 1-m² quadrat every 10 m along a linear transect. Approximately ten transects were created per plot. The Daubenmire method was used to determine the percent coverage of each plant species within the quadrats. The graph titled “Site Diversity,” (Figure 5) illustrates the plant biodiversities of each site, as well as the average biodiversity level for all of the plots combined.

We collected ticks in each plot over a three-day period in July 2014. We captured the ticks by dragging a 1-m² cloth on the forest floor behind us over a distance of 20-m. The ticks would cling to the cloth as we walked, and we collected them after each 20-m drag. This method was repeated until we had dragged the cloths across the entire surface area of the plots. The numbers of ticks captured were recorded, and the ticks were released. The graph titled “Ticks Before barberry Removal,” (Figure 6) illustrates the total number of ticks per square meter collected in each plot during the three-day tick collection period.
Figure 5: Plant biodiversity of plots 1-4 prior to Japanese barberry removal.

Figure 6: Tick densities of plots 1-4 prior to Japanese barberry removal.