Red Fox and Lyme Disease – Is there a Connection in Vermont?
October 2018

Background

In January 2018 the Vermont Fish and Wildlife Board received a petition to eliminate the hunting and trapping of fox "to help protect public health from Lyme disease and other tick- borne diseases." The petitioner was driven by the belief that the current level of harvest impacts the fox population and, consequently, that of small mammals, in particular, the white-footed mouse, one of the reservoirs of Lyme disease. The Board asked the Vermont Fish and Wildlife Department (VFWD)to review the current literature on the subject and report back to them at the October 2018 Board meeting.

Recommendation

After a thorough review regarding the influence of Vermont's red fox harvest on the prevalence of Lyme disease in the state, the VFWD finds no compelling evidence that the current rate of harvest of red fox is influencing the presence, distribution, or prevalence of infected black-legged tick (deer tick) on nymphs, the primary driver of Lyme disease. There are however, other meaningful strategies that may lesson the effects of Lyme disease which are listed at the close of the report.

Introduction

The petition required a thorough analysis of numerous complex interacting environmental relationships. In response, the Vermont Fish and Wildlife Department convened a team of scientists to work with the Vermont Department of Health in evaluating the breadth of factors influencing Lyme disease in Vermont. Department staff involved in the evaluation included Dr. Katherina Gieder, biometrician and research scientist, Kim Royar, furbearer biologist, Chris Bernier, assistant on the furbearer project, Nick Fortin, deer biologist, and Scott Darling, wildlife program manager. In addition, Dr. Bradley Thompkins, Epidemiologist and Program Chief, of the Vermont Department of Health provided expertise on the disease in Vermont.

Lyme disease, and the increasing trends in tick-borne illnesses, are a significant concern to all Vermonters, and therefore the VFWD recognized the value of an in-depth evaluation of those species under its purview and their relationship to these diseases. There are likely many interacting factors made more challenging to identify due to the number of predators on small mammals in Vermont including, but not limited to, bobcat, fisher, coyote, red and gray fox, weasels, hawks, owls, and snakes. This evaluation included a thorough literature review of the factors influencing Lyme disease in the state, collection of other VFWD data on related factors, analyses of fox harvest data and densities in Vermont, and recommendations on how the VFWD's management programs can contribute to State of Vermont efforts to address the disease.

The dynamics influencing the increase of the black-legged tick (*Ixodes sacpularis*) and subsequently Lyme disease in the region are incredibly complex. To date, it is difficult to speculate which of the many potential variables have had the greatest influence on the spread of the disease in New England. It is more likely that a combination of some, or all, of the multiple factors listed below (and perhaps some that have yet to be identified) have fueled the spread of the disease in Vermont. Following a description of the epidemiology (i.e., incidence, distribution, and possible control of diseases) of Lyme disease, this report evaluates the environmental factors below that could play a role in the presence and prevalence of Lyme disease in Vermont. They include:

1. Climate change
2. Habitat fragmentation
3. Invasive plants
4. Mouse population dynamics
5. Predators (including terrestrial and avian)
6. White-tailed deer densities

<u>Lyme disease across Vermont Health Department Assessment</u>

Lyme disease is becoming increasingly common in Vermont. When the state first started tracking the disease in 1990, fewer than 20 cases a year were reported to the Health Department. In 2017, the Health Department investigated over 1,000 reported cases. This increase has been driven by two general trends. One, a greater number of cases have been reported in parts of the state where Lyme disease has been common for several years. Two, cases have generally spread northward into parts of the state where Lyme disease was once rare.

Lyme disease is caused by an infection with bacteria called *Borrelia burgdorferi*, which is spread to humans through the bite of an infected blacklegged tick (*Ixodes scapularis*). These tick vectors are not born carrying *Borrelia burgdorferi*, instead they get infected early in their life cycle while feeding on animals that have the bacteria circulating in their blood. Small mammals that are common to Vermont, like the white-footed mouse (*Peromyscus leucopus*) and eastern chipmunk (*Tamias striatus*), are particularly well-suited to having the bacteria circulate this way, making them important reservoirs for Lyme disease. Because this interaction between reservoirs and vectors is crucial to maintaining Lyme disease in nature, factors that impact these animals, like habitat change, weather and food availability, can have an impact on human Lyme disease trends.

<u>The potential influences on the spread of Lyme disease</u>

A. *Climate Change:*

Climate change in the Northeast is predicted to result in rising temperatures and increased precipitation both of which could have a positive influence on tick nymph densities. It is believed that tick developmental phases will shorten with increasing temperatures (Ogdon 2006). In addition, warmer winters could increase the survivability of ticks, thus affecting the number of Lyme disease cases. Although, Brunner et al. in New York (2012) found that more than 80% of ticks survived the winter regardless of conditions. Werner et al. (2014) found that the warming climate was influencing the expansion of ticks into southern Ontario where they found higher than average minimum summer temperatures at ground level positively correlated to tick abundance.

The VFWD has collected winter severity data (WSI) for the last 30 years (number of days the temperature is below 0 degrees and snow depths are deeper than 18 inches). Figure 1 shows the declining trend in the overall statewide winter severity index since 1970.

Many other human pathogens such as malaria, yellow fever, dengue fever, and tick-borne encephalitis have also increased in either numbers or range (Harvell et al, 2002) over the same period. Although climate change has yet to be scientifically implicated, field and laboratory studies suggest a link based on the fact that (1) lower temperatures tend to increase the mortality of some vectors, (2) higher temperatures could increase vector reproduction and biting and (3) infection rates may also increase as temperature rises (Patz et al., 1998).

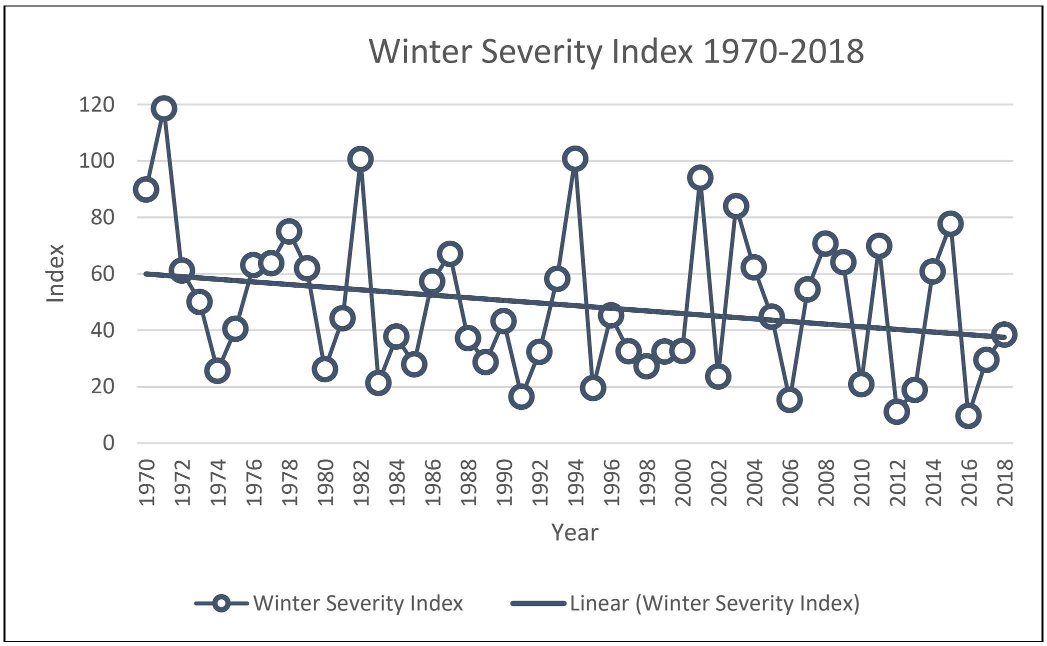


Figure 1. Vermont winter severity index 1970-2018.

B. *Habitat Fragmentation:*

Lyme disease has been found to be most prevalent in areas where "suburban and exurban development encroaches on deciduous forest ecosystems" in the northeastern U.S. (Ostfeld 2006). This could be linked to the fact that studies have found that both white-footed mice and deer mice populations are more abundant at the edges of woodlots than in interior forests suggesting that the parcelization, fragmentation, and development of our core forests could have a significant impact on the number of mice and ultimately the number of Lyme disease cases. Vessey (2007) found that smaller, isolated, forest patches often supported higher densities of small mammals. These smaller patches tend to concentrate mouse populations because dispersal is more difficult than between larger and/or interconnected patches (Nupp and Swihart, 1996).

These findings are in line with what has been found in other states around the country. Schmidt and Ostfeld have created the computer simulated graph (Figure 2) which suggests that as vertebrate diversity and species richness increases, the risk of Lyme disease decreases. Large, intact forest blocks tend to support a much healthier and diverse number of native species and a limited number of invasive plants. Allen et al. (2003) concluded that "the incidence of Lyme disease is particularly high in regions where dense human habitation is juxtaposed with forest habitat that supports tick vectors and their hosts (Barbour & Fish 1993). Results suggest that efforts to reduce the risk of Lyme disease should be directed toward decreasing fragmentation of the deciduous forests of the northeastern United States into small patches, particularly in areas with a high incidence of Lyme disease. The creation of forest fragments of 2.5 to 5 acres (1–2 ha) should especially be avoided, given that these patches are particularly prone to high densities of white footed mice, a low diversity of vertebrate hosts, and thus higher densities of infected nymphal blacklegged tick." Researchers (Allan et al 2003) speculate that the loss of biological diversity world- wide is related to an increase in the risk of infectious disease in humans.

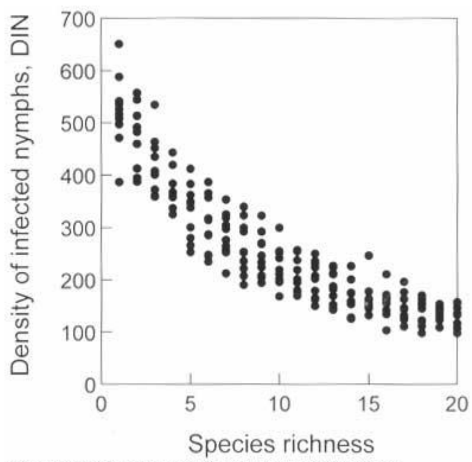


Figure 2. The relationship between species richness and the density of infected nymphs.

C. *Invasive Plants*:

Two non-native barberry species, Japanese barberry (*Berberis thunbergii*) and common barberry (*Berberis vulgaris*) have been implicated in the increase of black-legged ticks in forest environments. Barberry was introduced into the United States in the late 1800s as an ornamental and landscaping plant. It has adapted to the forests of New England and in recent years has become naturalized in many of our wooded environments. It is now a noxious invasive that can, with the help of deer who do not find it palatable, out-compete native regeneration. In addition, stands of barberry create perfect, humid environments for ticks. Dr. Scott Williams (2009) a professor at the University of Connecticut, has studied tick densities in barberry and has found that in areas where barberry is not controlled there can be upwards of 120 ticks per acre infected with the Lyme spirochete *(Borrelia burgdorferi)*. In areas where barberry has been contained, there were 40 infected ticks per acre, and only 10 infected ticks per acre where there was no barberry.

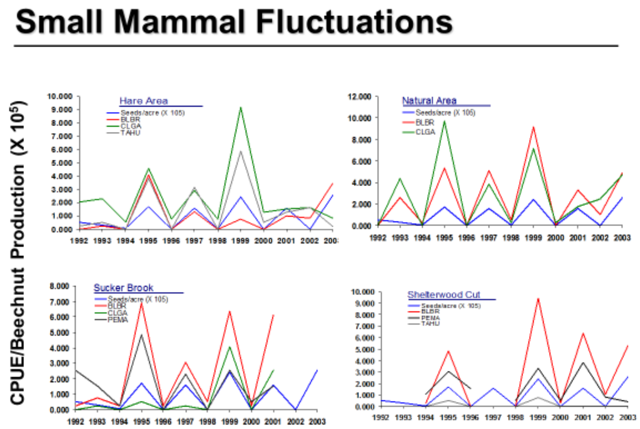
Barberry also provides excellent habitat for the white-footed mouse which efficiently distributes immature ticks over a wide area. The dense impenetrable stands of thorny plants protect mice from predators and provide excellent nesting areas.

Midwestern researchers (Allen et al. 2010) have studied the relationships among invasive honey suckle, white-tailed deer, and the abundance of lone star ticks. This study found that deer seek out dense stands of honey suckle to bed in because of their dense structure. In fact, they found stands of honeysuckle to be 18 times denser than native vegetation. In addition, honeysuckle is the first to leaf out in early spring and the last to lose its leaves in the fall which may create a unique microclimate for both deer and ticks. In his study, Allen (2010) removed honeysuckle and found that in the habitats restored to native vegetation the risk of exposure to tick pathogens was 10 times less than in those stands of dense honeysuckle. There are four invasive species of honeysuckle in Vermont and anecdotal information suggests that they also support high densities of the black-legged tick. The increase in non-native invasive plants has very likely influenced both the increase in small mammals, as well as, the increase in Lyme disease, at least in localized areas.

D. *Mouse Population Dynamics:*

Populations of small mammals fluctuate cyclically (Oli 2001). Although the driving forces behind these cycles is still not completely understood, it is believed that factors such as food, qualitative changes in individual animals, and/or predation can play a role in some species (voles, lemmings, and snowshoe hare). Many studies point to mast production as the driving factor in determining small mammal population densities. Krebs (1994) found that the exclusion of predators, although improving the adult survival of lemmings, was not sufficient to mitigate population declines due to the loss of juveniles. Several researchers have experimentally removed predators from islands in the Baltics and Finland and found "no significant effect on the abundance of voles during two cycles" (Krebs 1994).

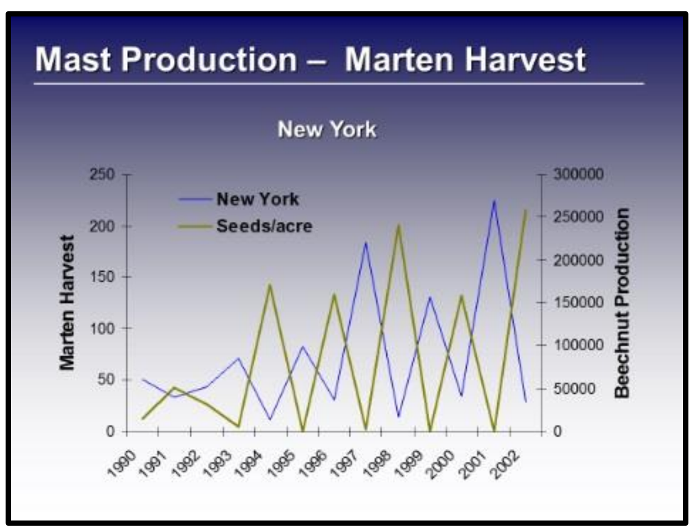
Ostfeld et al. (2006) also found that the strongest predictors of Lyme disease risk were the previous year's abundance of mice and chipmunks and the abundance of acorns 2 years previously. In other words, mast crops influence the density of small mammals one year later and the incidence of Lyme disease two years following that. **Ostfeld did not, however, advocate "cutting all the beech and oak to control rodent populations and minimize the risks of Lyme disease nor based on the evidence would he advocate to curtail all hunting and trapping of predators."** The graph below (Figure 3) demonstrates the influence of mast on small mammal populations. It is clear from this work done in New York, New Brunswick, and Maine (Jensen et al 2012), that small mammal populations are driven by the production of mast including acorns and beechnuts.



Paul Jensen (unpublished)

Figure 3. Small mammal densities and beechnut production.

Jensen et al (2012) found that between 1994 and 2006, beech mast production in New York, Maine, and New Brunswick was highly synchronized in an alternate year pattern. The resulting large pulses of available food every other year influenced the following summer small mammal populations of deer mice, red-backed vole, red squirrel, northern flying squirrel, and short-tailed shrew creating large fluctuations in their populations and resulting in a "bottom-up effect on the community." In addition, they found that marten and fisher experienced similar population fluctuations that were both immediate and time-lagged (Figure 4).



Paul Jensen (unpublished)

Figure 4. Mast production and harvest of pine martens in New York.

Some studies are available that provide density estimates of mice of the Peromyscus genus, or specifically its species most closely associated with Lyme disease, the white-footed mouse. A study in an isolated woodlot in Ohio concluded that female white-footed mice are territorial and defend a home range of approximately 500 m^2 (Vessey et al 2007) which, in appropriate habitat, could allow for 20 breeding females every 2.5 acres (1 ha) or 8 per acre. Vessey estimated that peak mid-summer populations of white-footed mice in this woodlot reached upwards of 40 mice per acre (100/ha). One other study estimated that summer population densities may reach 15 mice/acre (37/ha) (Timm and Howard, 2005).

As stated above, Peromyscus population cycles tend to be influenced by mast production. Vessey (2007) found that in years of low mast production (less than 5 nuts per m^2) the spring Peromyscus population was never more than 20 per 5 acres (2 ha; 4/acre) and summer not more than 100 per 5 acres (2 ha; 20/acre). If we assume a summer average of 15 mice/acre (likely a low estimate as numbers could be exponentially higher following high mast years) and we accept that the average town in Vermont is 30 mi^2, then we could theoretically (and conservatively) extrapolate the summer mouse population for each town to be upwards of 288,000 mice. If one fox eats an average of 5,500 mice/year than the removal of 2 to 4 foxes/town (likely a higher harvest than what we experience in Vermont) would have a negligible effect on the mouse population leaving upwards of 277,000 to 266,000 mice/town. The impact would be even less in fragmented landscapes as Peromyscus densities go up as forest patch size goes down (Nupp and Swihart 1996) adding credence to the hypothesis that fragmentation increases the potential for Lyme disease (see below).

E. *Predators:*

It is likely that as the wolf and puma were extirpated and Vermont's forests were cleared, the numbers of the more adaptable bobcat and red fox increased. Therefore, it is very possible that throughout the late 1800s and first half of the 1900s we had more red fox and bobcats than we have today. It has become accepted that competition and/or avoidance behavior exists between the various canid species (Voight in Novak, 1987) both for territory and food. Therefore, larger predators (coyotes, wolves, pumas) can functionally limit the population of meso predators such as red fox and bobcat. In Vermont, most of the predator species that currently live here eat a variety of small mammals including coyotes as confirmed by a food habits study conducted by Dr. David Persons in the 1980s. (Figure 5)

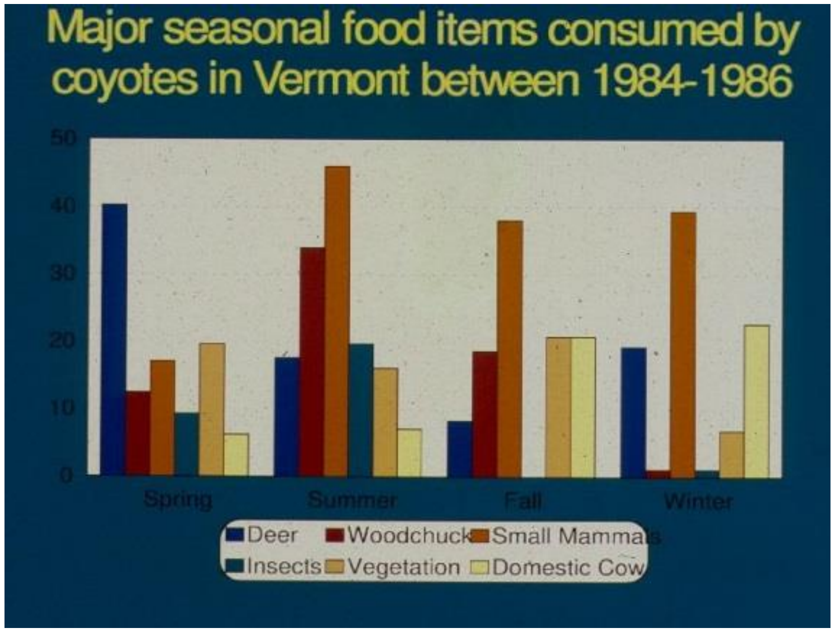


Figure 5. Coyote foods by season in Vermont (left to right spring, summer, fall, winter).

Hofmeester (2017) has postulated that predators can influence the rates of Lyme disease either by reducing the density of hosts or by influencing the behavior of prey (i.e. reduction in small mammal activity reduces the encounter rate with ticks). In addition, he speculates that small mammals that move more frequently and further, are likely to have a higher number of ticks and also an increased risk of predation thus essentially eliminating animals that are highly infested. He speculates that changes in predator abundance can have a cascading effect on tick-borne disease risk (Hofmeester et al. 2017).

Levi et al. (2012) also suggests that the increase in the incidence of Lyme disease in the Northeast is related to the "rarity" of red fox due to the expansion of coyotes into the region. Way and White (2012) disputes this hypothesis based on a variety of criteria including that coyotes also eat small mammals and that both red fox and rodent populations fluctuate due to outside factors (e.g., weather, disease, mast). In addition, the potential effects of fragmentation, climate change, and invasive plants, as well as, the fact that predator species have shifted over time from the original inhabitants: eastern Canadian wolf and the gray fox to coyote and the red fox are also factors that point to a much more complex relationship here in the Northeast, than what has been outlined by both Levi and Hofmeester.

Red fox are generalist predators although in Ontario meadow voles constituted up to 50% of the fox's diet. Mice, woodchucks, rabbits and snowshoe hare can also be important prey species along with a variety of birds, eggs, fruits, and insects. Captive fox pups have been known to require 3 to 4 pounds of prey/week (60-80 mice/week; 3,159-4,212/year), older pups 5.5 pounds (111 mice/week; 5,792/year), and adults 5 pounds/week (100/week; 5,265/year). (Sargeant, 1978).

As wildlife managers it is important to understand the factors that can influence predator populations and the role that hunting and/or trapping might play in altering those populations, if at all. Recognizing the value of predators and managing for sustainable populations is the responsibility of the Department and one we take very seriously. Maintaining healthy, intact ecosystems in the face of increasing development, fragmentation, habitat loss, and climate change has been a focus of many of the Department's efforts for the last 30 years. The result, thankfully, has been a healthy and intact system in Vermont. In fact, many of our predator populations are more common today than they were prior to European settlement (coyote, gray fox, bobcat, fisher) and many hawks and owls have recovered from the significant mid-20th century decline as a result of the wide-spread application of DDT.

F. *White-tailed deer populations:*

White-tailed deer are an important host of adult blacklegged ticks, and several studies have suggested a correlation between deer abundance and tick abundance (e.g, Kilpatrick et al. 2014, Werden et al. 2014). However, deer themselves are not susceptible to Lyme disease and are not a competent reservoir of the disease (i.e., a tick cannot become infected by feeding on a deer). Efforts to control deer abundance to reduce tick abundance have shown mixed results, but evidence linking deer reduction to reduced human Lyme disease risk is lacking (Kugeler et al. 2015). Most of these studies reduced deer abundance from extremely high densities (50->200/mi^2) to the higher end of densities currently found in Vermont (20-30/mi^2). Additionally, Ostfeld et al. (2006) found that once deer densities met a relatively low threshold, further increases in abundance had little, if any, effect on the densities of the nymphal stage of ticks. Rather, Ostfeld, suggests that as stated above, productive mast crops drive increases in rodent populations which then gives rise to an increased density of nymphs the following year. Importantly, the rapid increase in Lyme disease over the past two decades has not coincided with any substantial change in deer abundance in Vermont.

Fox Population Dynamics

Fox Life History

There are currently two species of fox inhabiting Vermont, the red fox (*Vulpes vulpes*) and the gray fox (*Urocyon cinereoargenteus*). The red fox is the larger of the two species and is found in a variety of habitats but in the Northeast are generally associated with agricultural habitats. The gray fox, on the other hand, is more often found in wooded, brushy, or rocky areas (Fritzell in Novak 1987).

The original European settlers arriving on the eastern shores of the United States may not have encountered the red fox as it was absent from much of the area (possibly including most of Vermont). The native gray fox inhabited the deciduous forests of the eastern states north to Vermont and New Hampshire. Some speculate that prior to European settlement, the southern limit of the red fox was the Vermont/Massachusetts border while others suggest that red fox were not found south of the Canada/Vermont border.

As the forests of Vermont were cleared in the 1800's; however, Zadock Thompson writes in his book: **The Natural History of Vermont** in 1853 that red fox were the most common fox and that "*the gray fox Canis virginianus', is said to have been taken in this state, but as I have seen no Vermont specimen, it is here omitted.*" It is likely that the agriculturally adapted red fox spread southward and became more common in the early and mid- 1800s likely as a result of the drastic human-caused shift in habitat from forest to farm, and the consequent elimination of other competing predators such as wolves and mountain lions. Zadock Thompson's 1853 assessment may have been, at least in part, due to the drastic changes that occurred on the landscape in the 50-60 years prior to his assessment. In fact, there was a bounty on fox in Vermont on and off between 1832 and 1904 with little effect on the population.

To complicate matters further, European red foxes were introduced by settlers and, until relatively recently, some believed that the current eastern fox population was the result of interbreeding with these introduced animals. However, recent genetics analysis of the mid-Atlantic fox population suggests that the matrilineal ancestry of the east coast population is related to those in Eastern Canada and the Northeast (Stratham, et al. 2012) and not to the old- world red fox. Although red fox are also native to the high elevation boreal regions of the western United States, they were not found in the lowland areas there prior to European settlement. Genetics work by Stratham (2012) found that some of the fox populations in the northwestern United States are related to the native fox. However, they also found that populations in western Washington and southern California both contained haplotypes from other continents, perhaps a remnant of the fur farms that once existed there. These potentially non-native animals threaten many native species, particularly ground nesting birds. In response there have been long-term attempts in parts of the west to eradicate them (Kamler and Ballard 2002).

Today, the red fox is the most widely distributed carnivore in the world and exists throughout most of North America, Europe, Asia, and Australia where it was also introduced (Voigt in Novak et al. 1987). The species is regarded both as a nuisance and as a valuable predator by disparate publics around the world. It is an extremely adaptable species that is resilient to both human changes to the landscape, as well as to intense harvesting and, in cases where they have been introduced, eradication attempts. Like other canids, red fox populations subject to high losses (e.g., hunting, trapping, rabies, gassing, road kills) experience an increase in fecundity rates. The Province of Ontario has documented as many as 14 to 17 pups in a litter in areas where populations are impacted by rabies and high harvests. This is much higher than the average litter size of 3 to 6 pups.

Predators are an important part of the ecosystem for the many complicated roles they play in maintaining landscape diversity. It is likely that in Vermont, fox populations, along with bobcats increased after European settlement resulted in the elimination of wolves, mountain lions, and lynx and the clearing of 65%-70% of Vermont's forest habitats. The more resilient red fox and bobcat increased in number in response to the elimination of these top predators. For many years we had an unusually high number of these two meso carnivores in Vermont. Reduction in deer numbers, the maturation of the forest, and the immigration of coyotes all contributed to a realignment of these species more in line with what might have existed prior to European settlement.

The Department does not dispute that a severe reduction of predator populations to the point of "rarity" could influence small mammal populations and potentially other competing predators. However, today, species that are legally trapped and hunted are common and abundant and it is the Department's mission to maintain populations at levels that allow them to be enjoyed by all Vermonters. Many predator species have increased in the last 30 to 40 years including coyote, fisher, marten, and bobcat in the face of hunting and trapping pressure. In addition, many other predators such as hawks, owls, snakes, weasels, red and gray foxes, and mink, are well distributed and common across the landscape.

How many fox do we have in Vermont and how are they distributed?

In 2017, the USDA Wildlife Services estimated Vermont's red fox population to be slightly more than 5,000 animals. This is a very conservative estimate as it is based on the assumption that only 50% of the landscape (agricultural regions) functions as fox habitat. It is true that these areas may support the highest density of red fox in the state. However, we know from lynx and marten camera studies conducted in recent years by a PhD candidate (Alexej Siren, unpublished) on the Green Mountain National Forest (USFS) and in the Northeast Kingdom, that fox are not "rare" but are well distributed and common throughout these areas as well (Figure 6).

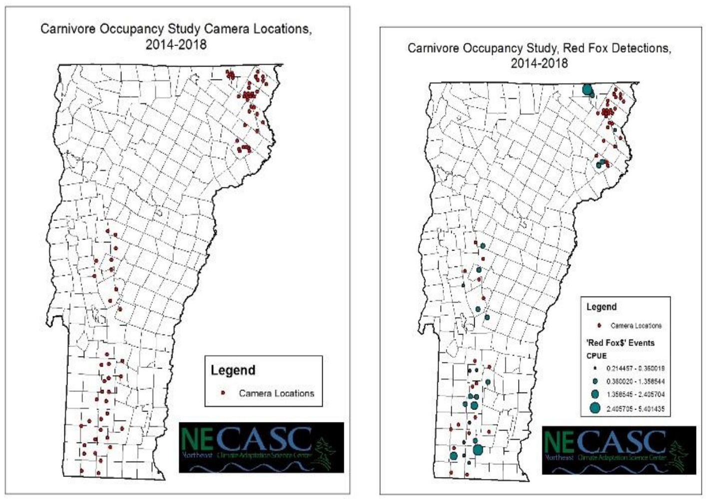


Figure 6. Camera (left) and Fox (right) distribution within the Green Mountain National Forest and the Northeast kingdom of Vermont.

Voight (Novak 1987), a leading researcher of red fox in Ontario, acknowledges that "accurate estimates of fox population size are not feasible for most areas". He did however, after 6 years of intensive research into fox family numbers, estimate the population in the southern part of the Quebec Province to be around 2.6 fox/mi^2 during the spring (Voight in Novak, 1987). In areas of good habitat, he observed up to 3 times this estimate. If we apply the same densities in Vermont, an average town could potentially support approximately 78 red fox in average habitat and upwards of 234 in pockets of high-quality habitats. If we extrapolate these average town densities to determine a statewide population estimate, we could expect close to 3 times the Wildlife Services estimate of 5,000 red fox. However, competition from coyotes likely limits these reported densities in most areas of the state and therefore the statewide population is likely somewhere between 5,000 and 10,000 animals.

<u>Factors Affecting Fox Populations:</u>

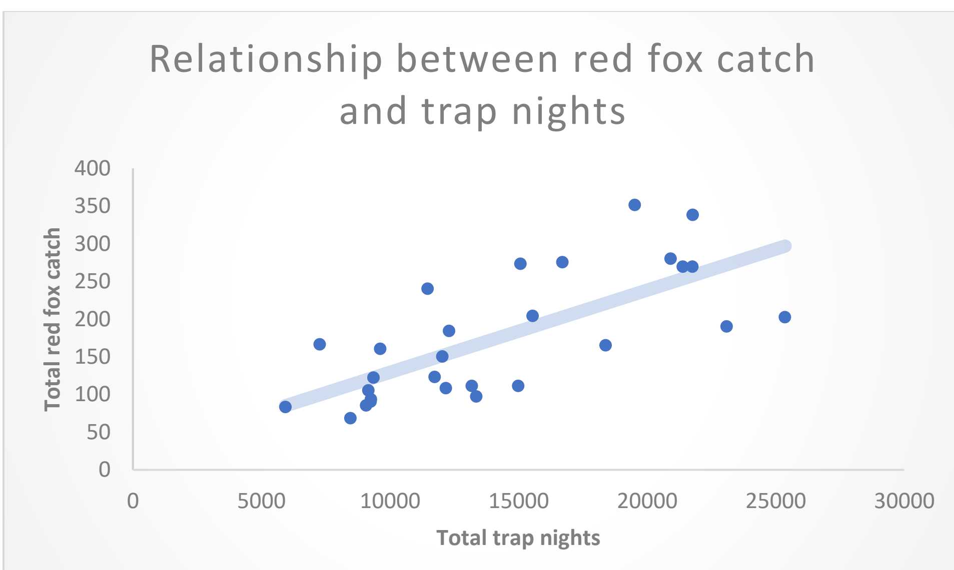
A. *Trapping and Hunting in Vermont*

   The large variety of habitats that red fox can thrive in and the wide range of different sizes of habitats they call home (Walton et al. 2017) make it impossible to accurately estimate red fox populations without exorbitant funds and time investment. State agencies have limited capacity and must be strategic as to where to focus their time and effort. The best and only indicator of red fox populations that currently falls within the limited resources of Vermont

Fish and Wildlife is catch per unit of effort (or CPUE) data collected from an annual trapper mail survey. CPUE trends over the long term can inform our knowledge of general population patterns that we can analyze in conjunction with trends in trapping activity. From this information, we can infer the following: 1) long-term sustained population changes; 2) short-term population changes associated with changes in food sources or disease outbreaks; and, 3) large scale changes across multiple states and regions.

Analysis of CPUE patterns thus far indicate that the red fox population in Vermont likely fluctuates widely from one year to another, which is not surprising given that the main food source for red fox, small rodents, tend to be characterized by cyclic population changes (periods of population booms followed by busts and back again). CPUE values also do not show any linear trend over time. In other words, the population as indicated by CPUE trends is not experiencing any sustained population increase or decrease that can be detected by any statistical model. A linear regression of CPUE trend over time reveals a statistically valid decline over time of approximately 0.00023 red fox per trap night every year. However, the variation in these CPUE values, and the small sample sizes from a low number of trappers, makes a linear regression analysis completely invalid for assessing red fox population trends. Tests of model assumptions, including values of R^2 (0.20) and residual plots (clear grouping pattern), clearly indicate that CPUE do not follow any sort of linear trend over time. Instead, they appear to undulate over the long term, increasing and decreasing due to a variety of large-scale factors, such as small rodent populations, disease, and competition with other predators, most notably coyotes as recent research has highlighted.

Correlation analyses between trap nights and red fox catch indicates a strong relationship (correlation coefficient of 0.71), meaning that as trap nights increase, red fox catch also increases proportionally.



If trapping were affecting red fox populations, you would expect a weaker or even negative correlation because catch may go down or at least not increase as proportionally as trap nights increase. Presumably, this correlation is strong because there are plenty of red fox available for trapping every year, even though their populations may fluctuate in a non-linear fashion. These results align with long- and well-established understanding that red foxes are an incredibly flexible species that have highly adaptable diets, habitat needs, behavior, and socialization, as described below.

There appears to be no particular trend over time in CPUE for gray fox. In addition, statewide harvest numbers are so low (59 in 2017; 21 in 2016) that the influence of harvest on population densities is likely insignificant. Perhaps as importantly, there is no evidence in the literature connecting gray fox to white-footed mouse populations or Lyme disease.

A. *How does the harvest of fox influence the population*?;

Red fox are an incredibly resilient species. They are among the most flexible of species when it comes to where they live, what they eat, how they behave, and how they socialize (Cavallini 1996, Baker et al. 2000). This flexibility has enabled red foxes to inhabit the entire northern hemisphere from arctic to temperate climes, in a wide range of different habitats from thick forests to dense cities (St-Georges et al. 1995, Contesse et al. 2004). Their ability to modify their diets, behaviors, and social structures also makes them very resilient to large sustained changes in their populations. Previous efforts to reduce red fox populations in places where they have been introduced and are considered a non-native invasive species have found that multiple year efforts to control or eliminate the species have been unsuccessful.

For example, efforts to control the non-native red fox in Australia were unsuccessful even in the face of an annual removal of 50% of the population through trapping. These researchers (Harding 2001) found that "trapping did not cause the collapse of local fox populations and was unlikely to result in long-term declines."

Another study conducted in Western Australia found that density reduction in fox populations resulted in increased reproductive rates (Marlow et al., 2016) which is in keeping with what has been found by other researchers. Layne and McKeon (1956) found that even after a reduction of 64-76%, red fox populations were able to achieve full recovery in one year through changes in reproductive rates and increased immigration both of which are thought to undermine attempts to control or limit non-native fox populations. Lieury et al (2015) also found that harvesting fox during the pre-dispersal period, resulted in a return to the original population density by the following February. The removal of an average of almost 2 foxes/.38 mi^2 (km^2)/year over a 5-year period, did not result in a significant reduction in density over time. This is the equivalent of removing 158 fox in each town in Vermont each year for 5 years and a total statewide harvest of 39,632 animals.

Voight (Novak 1987) summarizes the resiliency of native red fox in the following statement:

> "The high fecundity and dispersal potential of foxes enable populations to withstand a high level of mortality. Even if the use of poisons and gas (illegal in Vermont) concurrent with a rabies outbreak decimated numbers, ingress and high reproduction would soon follow. Habitat destruction that reduces prey numbers will lower fox numbers to a greater extent than a short-term overharvest will. Gassing efforts have been widespread and persistent in

Europe, but they have had few long-term effects on fox numbers (Wandeler et al. 1974). …. the adaptability of red fox overrides the relatively small manipulation of populations through [harvest] management. In local areas, competitors such as coyotes or gray foxes, or diseases such as rabies, can have a great impact and are relatively uncontrolled."

B. *What other factors affect fox populations*?

Wildlife managers and researchers have all documented the cyclic nature of red fox populations even in the absence of intensive harvest or aggressive control efforts. While a clear understanding of all of the factors involved in influencing these cycles is still uncertain, many suspect that diseases such as mange, canine distemper, canine parvovirus, and rabies often play a role (Albmurg et al. 2009 in Way and White). In places where rabies is a factor, mortality of 60-80% has been documented during outbreaks (Voight et al. 1985). Although it is speculative, it is also possible that fox populations, like other predators such as marten and fisher, respond to the cyclic nature of mast crops and the subsequent boom and bust cycle of small mammals.

In the last half century, Vermont's red fox populations have been significantly influenced by the immigration of coyotes into the state. Many studies have documented competition and/or avoidance behavior between the various canid species (Voight in Novak, 1987, Ingalls, 1990). Research done in Vermont in the 1980s on coyote, red and gray fox, found the home range of red fox to average .77 mi^2 (Ingalls, 1990) smaller than what was reported in mid-western and eastern states at that time. Ingalls also found that "Red fox and coyote home ranges were largely mutually exclusive". Coexistence with coyotes appeared to be the result of two different avoidance strategies. Both red and gray fox maintained similar separation distances from coyote core areas. In addition, red fox home ranges were located in boundary areas between coyote group home ranges, thereby maintaining spatial separation from coyotes. According to Ingalls: "Gray fox, on the other hand, overlapped coyotes to a greater degree on a spatial basis, but avoided coyote core activity areas and avoided coyotes on a temporal basis, probably through behavioral means." It is unclear whether the fact that gray fox can climb trees plays a role in the overlap. In addition, there has been some evidence that gray fox, though smaller, actually out-compete or dominate the red fox in some parts of its range (Follman, 1973).

Factors affecting red fox mortality have shifted in the last 30 years in the Midwest as a result of changes in interactions with coyotes, humans, and habitats. During this time, trapping and hunting furbearers decreased two-fold nationwide (International Association of Fish and Wildlife Agencies 1992). During that same period coyotes have expanded their range and agricultural practices in the Midwest have resulted in increasing degradation of quality fox habitat. Gosselink (2007) hypothesized "that red fox survival and sources of mortality have changed over the past decades due to changes in coyote prevalence, hunting and trapping pressure, and habitat alterations." Fox mortality studies done in both urban and rural Illinois, found that of 335 radio telemetered rural foxes, 40% were killed by coyotes, 40% by vehicles, 7% from hunting, 2% from mange. Conversely, 45% of urban foxes died from mange and 31% from vehicles (Gosselink, 2007).

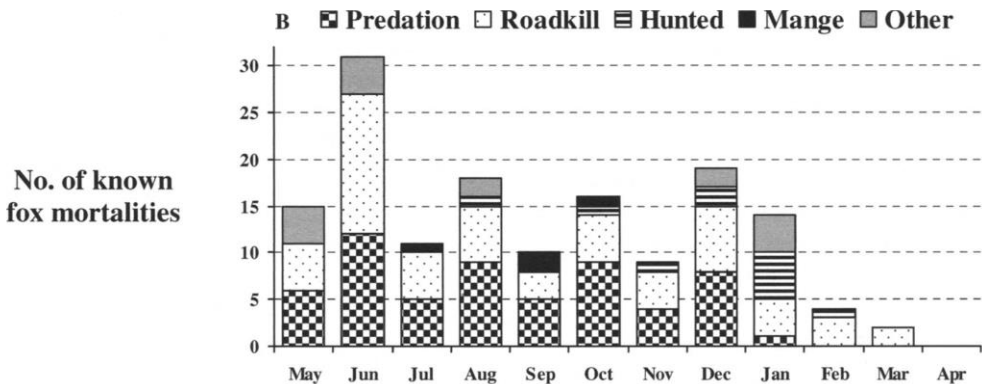


Figure 8: Mortality sources and timing for rural foxes in east central Illinois (Gosselink 2007).

Gosselink (2007) concluded that coyote predation had essentially replaced hunting mortality since the 1970s. In addition, vehicle mortality was higher in rural fox populations than in urban areas. The researchers speculated that coyotes pushed foxes into using denning sites closer to the human interface (e.g., road culverts) where they were more vulnerable to vehicle mortality.

In regions where mortality is high (i.e., from hunting, trapping, disease, road kills), reproductive rates are correspondingly high as well, while some urban areas in Great Britain with extremely high densities and lower mortality (78 fox/mi^2) have much lower fecundity rates (Voight and MacDonald, 1984 as sited in Novak).

Recommendations

The VFWD manages and conserves Vermont's wildlife species in trust for the people of Vermont. This includes the varied public interests in Vermont's wildlife, as well as, ways to address public health, safety, and quality of life. For this reason, the VFWD has conducted this in-depth evaluation of the various environmental factors influencing the presence and prevalence of Lyme disease in the state.

After a thorough review of the petition's concern regarding the influence of Vermont's fox harvest on the prevalence of Lyme disease in the state, the VFWD can find no compelling evidence that the current rate of harvest of foxes is influencing the presence, distribution, or prevalence of infected black-legged tick nymphs, the primary driver of Lyme disease.

This evaluation does however, underscores the importance of continuing the ongoing Department work, along with other state agencies and partners, to address the key factors below that likely affect the prevalence of Lyme disease and other tick-borne illnesses.

1. *Maintain large blocks of intact forest and connectivity between them (implement VCD)*

   Because black-legged ticks and subsequently the incidence of Lyme disease could be tied to landscape fragmentation in the face of development and parcelization, as well as, the corresponding increase in invasive plants such as barberry and honeysuckle, we should work together to minimize these practices on the Vermont landscape. The implementation of the

Vermont Conservation Design (VCD) through a variety of approaches (education, acquisition, legislation, regulation, management, etc.) would result in many benefits for wildlife, forestry, and the working landscape and will also help to minimize the effects of Lyme disease.

2. *Work to mitigate climate change and increase resiliency.*

   Climate change is probably the biggest challenge facing humans in the next 10 to 15 years, not only because of its potential influence on black-legged tick populations but also because of the myriad and, to date, potentially unknown impacts to humans, wildlife, and our functioning ecosystem as we know it. Vermont citizens need to work together to address landscape resiliency, and the implementation of climate adaptations and mitigation strategies.

3. *Continue to work with partners and private landowners to reduce the spread of non-native invasive plant species.*

   Many programs currently exist to educate and work with landowners to reduce the number of invasive plants in our forests and fields. The Department participates in USDA Natural Resources Conservation Service (NRCS) cost-share programs to work with landowners and foresters to reduce species such as barberry, buckthorn, and honey suckle on both state and private lands. However, this will take a multitude of complex actions to effect real change on the landscape.

4. *Ensure that our valuable predator populations are managed sustainably.*

   Continue to monitor predator populations to ensure that they remain common and abundant on the landscape. This may include ramping up monitoring efforts for coyote and fox, given that the VFWD is already collecting in-depth information on our other furbearer predators. Recently, the VFWD has made some changes to its Point of Sale (POS) system to assist in collecting better information on the level of hunting of coyotes and bobcats and are considering options for reaching out to collect data related to numbers and effort.

5. *Manage Deer Populations to maintain densities within carrying capacity*:
   Continue to manage deer populations to ensure that densities are in line with carrying capacity. Where higher human population densities (i.e., exurban parts of Vermont) present obstacles to managing deer under state or regional regulations, consider establishing special management zones to better control deer populations. Additionally, focus on areas where non-native invasive plants are prevalent and in Wildlife Management Units where deer densities could increase due to warming winters and declining hunter numbers.

Compiled by Kim Royar, Furbearer Project Leader, Vermont Fish and Wildlife Department, October 2018

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