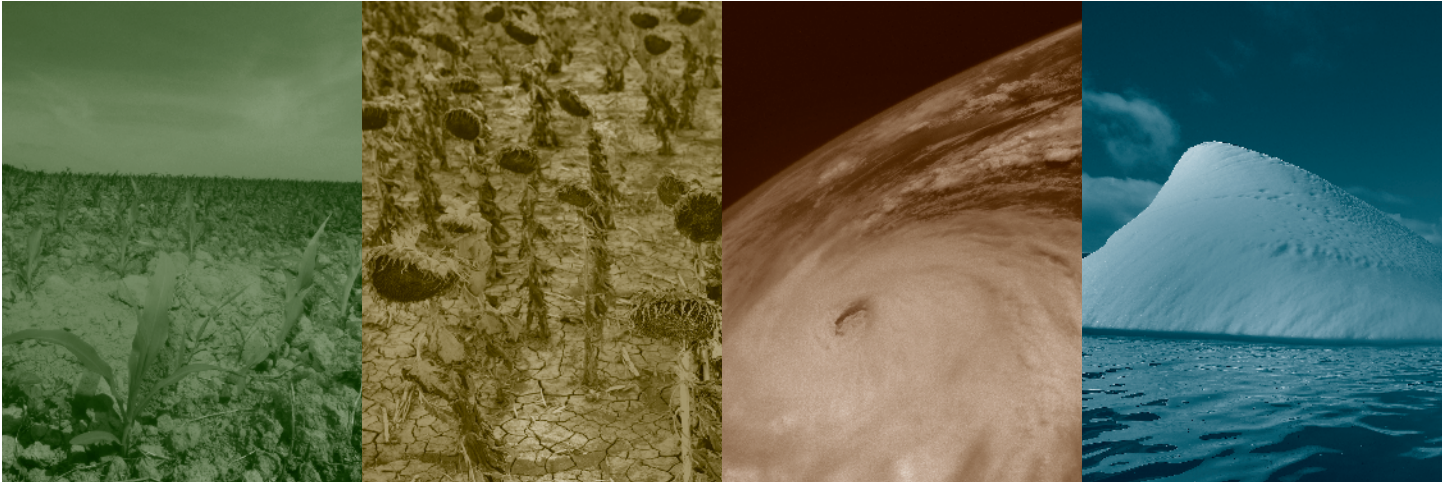


The Effectiveness and Implementation of 4-Poster Deer Self-Treatment Devices for Tick-borne Disease Prevention

A Potential Component of an Integrated Tick Management Program



Climate and Health Technical Report Series

Climate and Health Program, Centers for Disease Control and Prevention

Teresa J. Wong,¹ Paul J. Schramm,² Erik Foster,³ Micah B. Hahn,^{2,4}
Nathaniel H. Schafrick,⁵ Kathryn C. Conlon,² Lorraine Cameron³

¹*Master of Public Health Program, College of Health Sciences,
Des Moines University Osteopathic Medical Center, Des Moines, IA, USA.*

²*Climate and Health Program, Division of Environmental Hazards and Health Effects (DEHHE), National Center
for Environmental Health (NCEH), Centers for Disease Control and Prevention (CDC), Atlanta, GA, USA.*

³*Climate and Health Adaptation Program (MICHAP), Division of Environmental Health,
Michigan Department of Health and Human Services (MDHHS), Lansing, MI, USA.*

⁴*Division of Vector-Borne Diseases (DVBD), National Center for Emerging and Zoonotic Infectious Diseases (NCEZID),
Centers for Disease Control and Prevention (CDC), Fort Collins, CO, USA.*

⁵*Climate and Health Program, Division of Environmental Health,
Vermont Department of Health, Burlington, VT, USA.*



Executive Summary

In the last decade, the reported incidence of tick-borne disease has increased significantly in the United States.^{1,2} Climate change is projected to alter the geographic and seasonal distribution of existing vectors and risk of vector-borne diseases.³ Resilient public health preparedness efforts and climate adaptation plans could mitigate the anticipated change in tick-borne disease risk. Health departments and other local jurisdictions have a variety of options available to combat the spread of tick-borne illness. Assessing public health interventions, Step 3 of CDC's Building Resilience Against Climate Effects (BRACE) framework,⁴ is a necessary step before choosing an intervention strategy. This document seeks to provide guidance on one potential intervention activity, and provides a summary of peer-reviewed and grey literature to determine the effectiveness of the 4-Poster self-treatment bait station device for controlling tick populations among white-tailed deer (*Odocoileus virginianus*) hosts. Procedures for implementation of the 4-Poster device, occupational health and safety guidelines, and other considerations relating to 4-Poster device usage that may impact effectiveness are discussed.

While 4-Poster deer self-treatment devices are demonstrated to be moderately effective at controlling tick populations in small spatial scales with high device density under ideal conditions, there are several major potential barriers to effective implementation. The devices are not suitable for broad scale (e.g., county-wide) use and can be expensive to install and maintain long-term. While utilization of 4-Poster devices can result in a reduction in tick populations at localized spatial scales, this has not been directly correlated to a reduction in tick-borne illness. Additional concerns regarding 4-Poster operation are the potential for disease transmission between and among various wildlife species, pesticide exposure in workers and communities, and the lack of reliability of 4-Poster devices when acorns and other food sources are abundant (mast years). All of these factors limit the effectiveness of 4-Poster devices as an intervention for reducing tick populations. Still, there is evidence that under some circumstances, 4-Poster devices can be an effective means of controlling local tick populations when used as part of a larger integrated pest management (also known as integrated vector management, or specifically integrated tick management) strategy. Health departments should consider if this intervention is appropriate for their jurisdiction, if they have the authority and necessary partners to implement as part of a larger tick-control strategy, and whether the potential benefits outweigh the high costs and implementation barriers.

Background

Tick-Borne Diseases in the United States

Many species of ticks occur in the U.S.; however, not all species commonly bite or transmit pathogens to humans. Human-biting ticks can transmit diseases such as anaplasmosis, babesiosis, Colorado tick fever, ehrlichiosis, Lyme disease, Powassan disease, *Rickettsia parkeri* rickettsiosis, Rocky Mountain spotted fever, southern tick-associated rash illness (STARI), tick-borne relapsing fever (TBRF) and tularemia⁵ There are other newly emerging tick-borne diseases that are currently being identified, such as *Borrelia mayonii*, *Borrelia miyamotoi*, Heartland virus, and 364D rickettsiosis.⁵ The pathogen *Borrelia burgdorferi*, transmitted by the blacklegged tick (*Ixodes scapularis*), causes Lyme disease, the most frequently reported vector-borne illness in the U.S.⁶ (see Figure 1). Estimated medical expenditures in the U.S. for Lyme disease alone are “between \$712 million and \$1.3 billion a year.”^{1,7}

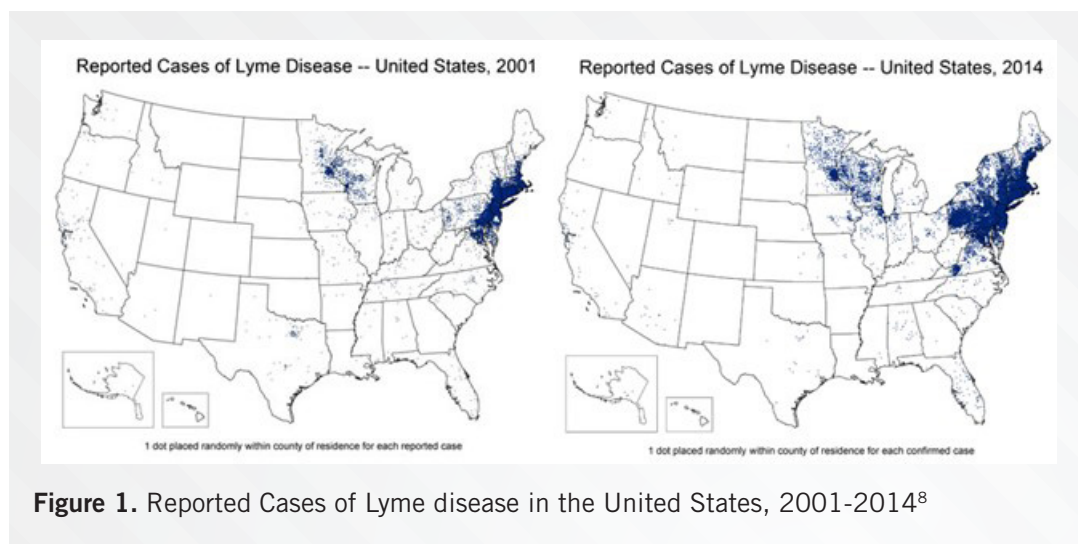


Figure 1. Reported Cases of Lyme disease in the United States, 2001-2014⁸

Geographic Distribution of Medically-Important Ticks in the United States

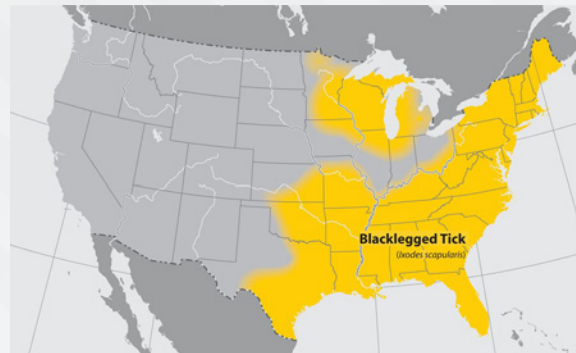


Figure 2. Geographic Distribution of the Blacklegged tick (*Ixodes scapularis*)⁹

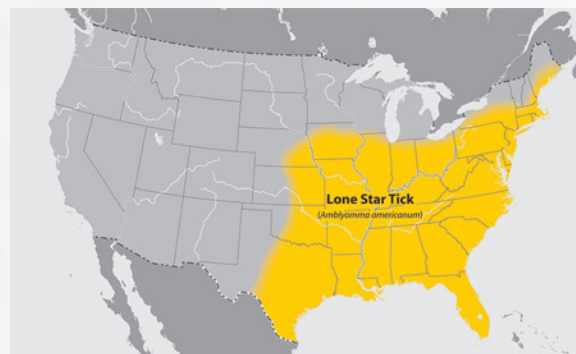


Figure 3. Geographic Distribution of the Lone Star Tick (*Amblyomma americanum*)⁹

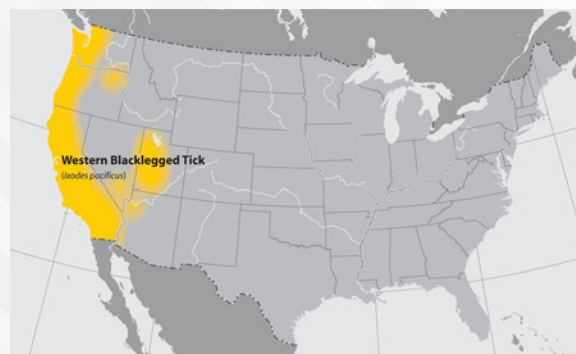


Figure 4. Geographic Distribution of the Western Blacklegged Tick (*Ixodes pacificus*)⁹

The Ecological Cycle of Hard Ticks in the United States

Ticks are arthropods and obligate blood-feeders. The peak activity period for ticks is spring and summer, but can extend into the fall in some regions.⁹ The life cycle for hard ticks generally consists of four stages: egg, larva, nymph, and adult; in order to survive, ticks must feed at each stage of their life cycle after they have hatched^{9,10} (see Figure 5). After mating, adult female hard ticks feed on a final blood meal for several days before laying thousands of eggs.¹¹

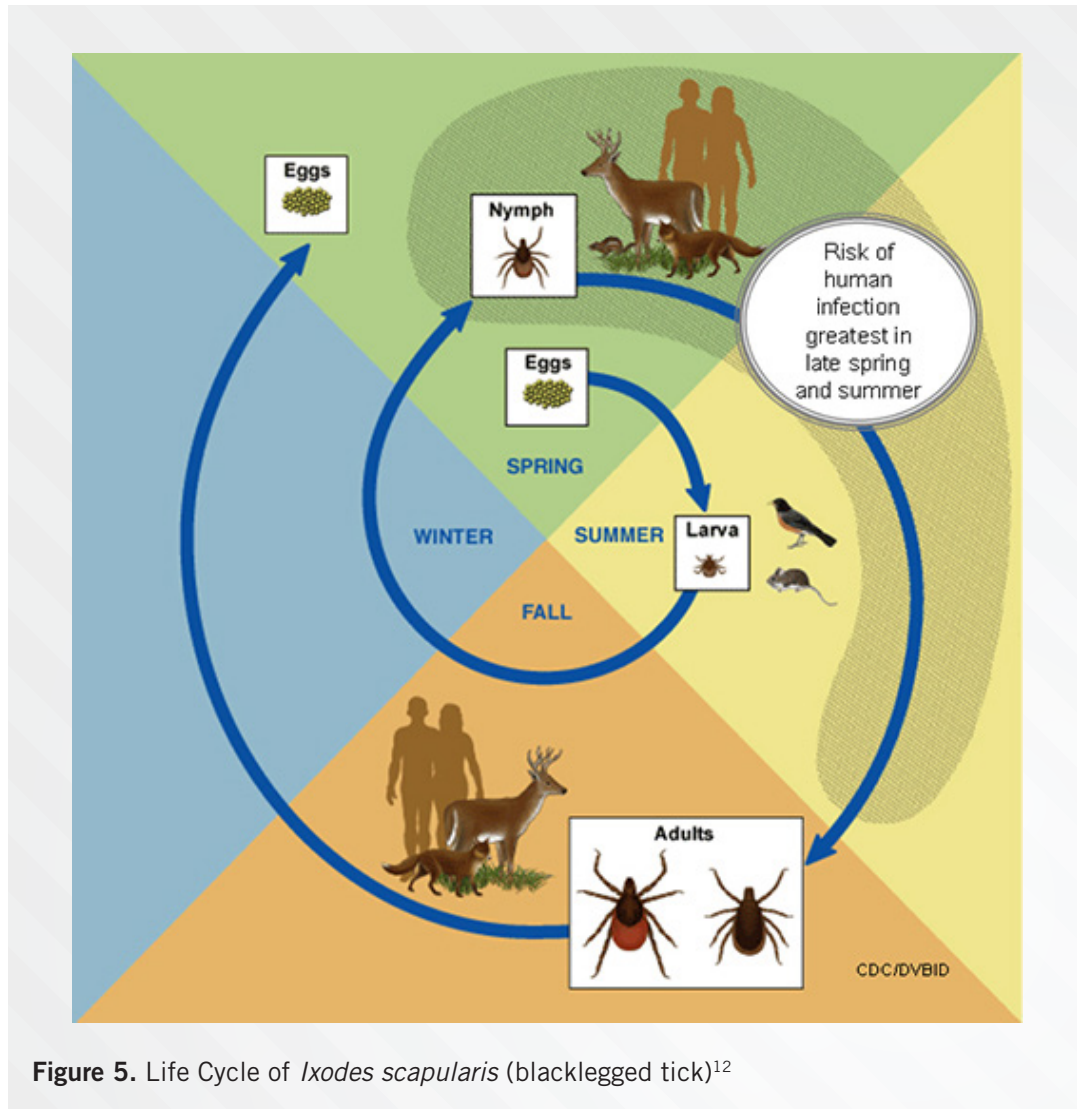


Figure 5. Life Cycle of *Ixodes scapularis* (blacklegged tick)¹²

Ticks feed on various hosts, including mammals, reptiles, birds, and amphibians.¹⁰ As seen in Figure 5, nymphal and adult blacklegged ticks prefer to feed on mammals, which include white-tailed deer.¹² Population levels of white-tailed deer have been associated with *I. scapularis* tick abundance in Lyme disease endemic regions of the United States.^{13,14} Reproductive stage ticks utilize white-tailed deer predominantly for their final blood meal and to find mates. Ticks will often feed in great numbers in the head, ears, and neck area of deer, and deer also play a role in the migration of ticks to new areas. The presence of deer therefore plays an important role in maintaining tick populations.^{15,16}

Influence of Temperature, Precipitation, and Humidity on Ticks

Temperature, precipitation, and humidity influence tick distribution and seasonality.^{3, 17, 18, 19, 20, 21} These meteorological factors are influential in tick host-seeking behavior, and could also play a role in disease transmission.²² Higher humidity is favorable for tick survival,²³ and tick activity, which increases during the presence of warmer ambient temperatures, may be influenced by longer seasons of warm weather, which allows for earlier emergence and extended tick feeding seasons.²¹ Warmer temperatures may also allow for the introduction of newly emerging or re-emerging communicable diseases.³ Additionally, changes in precipitation may shift the habitats that are suitable for tick population growth.^{22, 24} Modeling of the potential future geographic distribution of ticks shows that climate may play a role, and habitats may become suitable for ticks in many areas where tick populations are not currently established.²⁵

Despite the known links between temperature, precipitation, and humidity and tick life cycles, there is still uncertainty about how climate change driven changes in weather will impact tick populations.³ Due to the complex interactions between ticks, hosts, and the environment, the effect that climate change will have on these variables is difficult to predict.³ A variety of climatic factors and stressors will disturb ecosystems, impact host populations, alter the vector-host-pathogen transmission cycle, and impact the adaptive capacity of both human and wildlife species.³ While most models project a dramatic range expansion of *Ixodes* ticks and tick-borne disease, the specifics of the projections vary widely based on the models assumptions, and further research is necessary.²⁶

Interventions

There are numerous prevention and intervention measures established for tick control and mitigation. These interventions include the use of insect repellents for people and repellent-impregnated collars for companion animals, repellent-treated clothing, public education, environmental acaricide (pesticide that targets ticks and mites) spraying, landscape maintenance, deer culling and exclusions, tick traps, mouse bait boxes, and ivermectin-treated posters (which targets white-tailed deer with a medication to kill attached ticks). Despite the variety of interventions, few have been rigorously tested in the field. There is some evidence that environmental spraying of plant-derived acaricides can reduce tick populations,^{27, 28, 29} wearing repellent-impregnated clothing can reduce human tick exposure,^{30, 31, 32} and education campaigns may also affect tick exposure,^{33, 34} although none of these potential interventions have been tied directly to a measured decrease in tick-borne illness. There are concerns regarding the ethicality and adverse health effects of some tick-borne interventions, such as environmental damage from habitat modification, potential negative effects of insecticides on non-target species, impact of human exposure to acaricides, and the public's opposition to deer culling.³⁵ Any intervention should be used as just one part of a comprehensive integrated tick management program. The Michigan Department of Health and Human Services conducted an assessment of tick-borne disease interventions and concluded that 4-Poster bait stations have received considerable attention in the scientific literature (pending publication). This document provides an overview of the effectiveness and limitations of 4-Poster deer self-treatment bait stations.

4-Poster Intervention

The 4-Poster deer self-treatment bait station, designed to mitigate tick abundance among key hosts such as white-tailed deer, is a patent of the U.S. Department of Agriculture's Agricultural Research Service.³⁶ The device is comprised of a centralized bin containing whole kernel corn utilized for bait, with attached feeding stations and appendages on each side of the central bin³⁶ (see Figure 6). The appendages hold paint roller applicators made from fibrous material, which rotate on PVC pipes connected to the adjacent feeding bins.³⁶ A plate partially occludes each feeding station, forcing contact between the acaricide-charged applicators and deer as they feed³⁶ (see Figure 7). In evidence-based literature, researchers administered a 10% permethrin formula on the rollers to target ticks attached to white-tailed deer hosts. As deer feed, the paint roller applicators transfer acaricides onto the head, neck, and ears of the deer, which disperse to the remainder of the body through self-grooming.



Figure 6. 4-Poster Bait Station³⁷



Figure 7. Buck Feeding on 4-Poster Bait Station³⁸

Literature Summary: Effectiveness of the Intervention

Control of *Ixodes scapularis* (Acari: Ixodidae) with topical self-application of permethrin by white-tailed deer inhabiting NASA, Beltsville, Maryland, 2003

Solberg et al. (2003) implemented four 4-Poster devices charged with 1% and 10% permethrin in enclosed areas at Goddard Space Flight Center, National Air Space Administration (NASA), Main campus, Greenbelt, MD.³⁵ Patuxent Wildlife Research Center, Central Tract, Laurel, MD, which was partially enclosed, was selected as the control area.³⁵ The NASA facility was approximately 255 hectares, while Patuxent Wildlife Research Center had an area of 1,010 hectares. The 4-Poster devices were placed approximately 10 to 15 meters inside wooded areas, and each bin was filled with 225 pounds of whole corn.³⁵ The 1% permethrin solution was replaced with a 10% permethrin solution after the first month of treatment. The 4-Poster devices were initially equipped with foam paint rollers charged with permethrin. Two years through the study, the foam rollers were replaced with fibrous paint rollers due to missing pieces of foam removed by small mammals for consumption or nesting material.³⁵ The authors deployed bait, such as corn and apple slices, to lead deer to feeding stations. The authors found the utilization of trough plates during inclement weather as an effective method for closing off corn from becoming wet or moldy.³⁵ In June 1996, the authors observed the use of the 4-Poster devices by 30 non-target Canadian geese (*Branta canadensis*).³⁵ To prevent the geese from feeding from the devices, the authors placed the devices on concrete blocks. Other animals observed feeding from the 4-Poster devices were “gray squirrels, *Sciurus carolinensis*; gray foxes, *Urocyon cinereoargenteus*; rac[c]oons, *Procyon lotor*; white-footed mice; eastern chipmunks, *Tamias striatus*; American crows, *Corvus brachyrhynchos*; and small unidentified passerine birds.”³⁵

Data collection techniques included marking deer using a dye, dragging for tick samples, examining ticks on deer, and sampling mice for ticks.³⁵ During the study, Solberg et al. (2003) found that deer that were the furthest distance from 4-Poster devices had permethrin in their pelage, demonstrating that the deer had traveled greater than 1000 meters to eat from the feeding station.³⁵ The use of the permethrin acaricide resulted in a 78% decrease in nymphal and 100% decrease in adult blacklegged ticks, increasing to a 100% reduction in both adults and nymphs for the second and third year of treatment.³⁵ The authors discuss 4-Poster non-target usage, replacement of foam rollers to fibrous rollers, and the need to change corn suppliers (due to the presence of corn meal and corn fines) as issues that manifested during the study.³⁵ Although the authors found the confined 4-Poster devices to be more environmentally friendly than area-wide spraying, and 4-Posters were observed to be effective in controlling tick populations, continued research is needed. Solberg et al. (2003) provided future recommendations to rotate acaricides in order to prevent permethrin resistance in ticks, continue 4-Poster devices with permethrin to determine if the device is still effective in reducing tick populations, and to develop

bait stations for non-target wildlife species that may be hosts for blacklegged ticks.³⁵ A potential limitation of this study is that it was conducted on a small (255 hectare) fenced-off NASA property, and thus the findings may have limited applicability to effectiveness of 4-poster devices on larger, open tracts of land.

Evaluation of 4-Poster Acaricide Applicators to Manage Tick Populations Associated with Disease Risk in a Tennessee Retirement Community, 2011

Harmon et al. (2011) operated eight 4-Poster devices charged with 10% permethrin at a 5,260 hectare retirement community in Tennessee to reduce lone star tick populations, assess the retirement community's current tick mitigation plans, and evaluate the effectiveness of 4-Poster devices among larger-scale communities in real-world settings.³⁹ With a permit, the managers of the retirement community operated the 4-Poster devices at eight sites in the northern and southern portions of the community from April through September, recharging the bait stations weekly. The authors moved 4-Poster devices due to complaints of deer-vehicle collisions and poaching concerns.³⁹ They flagged for ticks, which revealed a higher density of adult and nymphal lone star ticks in the northern half of the community than the southern half. Higher tick populations and disease risk has been noted to be considerably higher in the northern half of the community due to its shared border to a 32,370 hectare wildlife management property.³⁹ The authors observed a statistically significant treatment effect on nymphal and adult lone star ticks that were within 300 meters from the 4-Poster device. The authors observed a higher reduction of nymphal lone star ticks than compared to adults within 40 square meters of the 4-Poster devices.³⁹ Larval lone star ticks revealed "an overall 90.1% reduction...compared to non-treatment sites."³⁹ A small effect size was observed among adult lone star tick populations, which Harmon et al. (2011) attributed to an insufficient number of 4-Poster devices in their large, 5,260-hectare retirement community and short duration of 4-Poster deployment.

The authors also employed trail cameras to monitor for other species utilizing the 4-Poster devices. Observed non-target wildlife species utilizing the 4-Posters consisted of squirrels, raccoons, turkeys, crows, woodchucks, wild hogs, and a grey fox.³⁹ The authors attributed the decrease in ticks within close proximity to 4-Poster devices to a high density of non-target wildlife hosts, which reduced the accuracy of drag sampling.³⁹ Harmon et al. (2011) also raised concerns regarding the potential for the 4-Poster device to serve as a fomite and transmit disease, although this was not measured in the study. Their recommendation for future strategies are to implement integrated tick management control measures, such as landscape management, exclusion fencing, and resident education.³⁹ The study noted that deploying 4-Poster devices at a sufficient density for large-scale deployment may be prohibitively expensive and it would be difficult to find suitable sites given restrictions on use in close proximity to residential dwellings. The data cited the need to consider integrated pest management techniques rather than solely relying on 4-Poster self-treatment devices to reduce tick abundance.

The Effectiveness of Permethrin-Treated Deer Stations for Control of the Lyme Disease Vector *Ixodes scapularis* on Cape Cod and the Islands: A Five-Year Experiment, 2014

Grear et al. (2014) deployed 42 4-Poster devices utilizing 10% permethrin in seven different treatment sites among Cape Cod, Martha's Vineyard, and Nantucket in Massachusetts over a five-year period to control for blacklegged ticks.⁴⁰ Four-poster devices were deployed from mid-August to mid-November and in mid-March to mid-June from 2007 to 2011, with one station per every 150 acres. Similar control sites were selected based on location, habitat, and prevalence of blacklegged ticks. Corn bait was replenished as needed, and permethrin was charged to the applicators at 7.5 mL per 50 pounds of corn consumed.⁴⁰ The authors recorded monthly corn consumption, amount of permethrin used to recharge the devices, the number of visits to 4-Poster devices, and the maintenance and replacements required for continued 4-Poster activity. Similar to the Northeast Area-wide Tick Control Project (NEATCP), Grear et al. (2014) flagged for ticks to calculate density and percent control. Swab samples were collected from the pelage of deer carcasses to test for permethrin residue analysis. The authors utilized Abbott's formula to calculate percentage control: $100 \times (1 - \frac{E_{t, \text{trt}}}{E_{t, \text{ctrl}} \times E_{o, \text{trt}}})$, where E represents the predicted mean abundance for control (ctrl) and treatment (trt) sites from baseline to end of treatment. The computed percent of control of blacklegged ticks following treatment demonstrated an 8.4% control.⁴⁰ They conclude that the effect size was much smaller than previous studies conducted in the USDA's NEATCP when using 2% amitraz.⁴⁰

Grear et al. (2014) attribute a smaller effect size to "landscape characteristics, deer density and vertebrate host community composition...and the density of 4-poster stations...deployed."⁴⁰ Additionally, when compared to previous studies, the authors suspected the difference in effect size to be due to the wide spacing between 4-Poster devices.⁴⁰ The recommended spacing for posters is one 4-Poster device for every 21 hectares, or one device per every 40 acres;^{41, 42} however, this recommendation could vary due to factors including associated habitats, deer density, and natural food availability. The authors discussed the limitations of utilizing a single tick control intervention and concluded that successful control methods would likely require "judicious application of an integrated approach consisting of multiple tactics."⁴⁰ They recommend further experiments and studies due to concerns of wildlife provisioning and contact between target and non-target wildlife species at 4-Poster stations, and its inability to represent a low-cost method for controlling Lyme disease except under certain conditions.

A Study Report on the Use of 4-Poster Deer Treatment Stations to Control Tick Infestations on White-Tailed Deer (*Odocoileus virginianus*) in Fairfax County, Virginia, 2016

Edwards et al. (2016) implemented 24 four-poster devices, using 10% permethrin, from February 2012 to March 2015 in Hemlock Overlook Regional Park (five stations) and Sully Woodlands (15 stations) in Fairfax, Virginia.⁴³ Two similar control sites, Laurel Hill Golf Course and Twin Lakes Golf Course, were selected. Data was collected by examining hosts for ticks, trapping ticks using carbon dioxide-baited sailcloth traps, monitoring use of the 4-Poster devices by non-target wildlife species, estimating deer density using infrared cameras, harvesting deer for a health examination, and assessments of environmental impact.⁴³

Data collection revealed a significant reduction in larval lone star ticks in both treatment and control sites; this suggests that something other than the 4-Poster device may have been impacting tick abundance.⁴³ Blacklegged ticks, however, saw no reduction in either treatment or control sites.⁴³ This result, however, could be influenced by the tick trapping method used. Carbon dioxide traps are not as effective for trapping blacklegged ticks as it is for lone star ticks.⁴⁴

Monitored use of the 4-Poster device revealed significant usage by non-target wildlife species. They reported “black bear, red fox, groundhog, raccoon, gray squirrel, Virginia opossum, Canada goose, and turkey vulture[s]” as species that utilized the 4-Poster device.⁴³ The estimates retrieved from infrared cameras demonstrated an increase in deer density over the treatment period, which the authors believed could have contributed to increases in deer population due to the continuous supply of food.

Deer health checks revealed no presence of Chronic Wasting Disease (CWD); however, there were deer with verminous pneumonia, enterocolitis [*sic*], organ inflammation, and parasites, although it is uncertain whether the prevalence of these conditions in the area deer was exacerbated by the presence of the 4-Posters.⁴³ This is certainly plausible, given the nature of the shared feeding confines of the 4-Posters. Fairfax County also examined the environmental impacts of 4-Poster deer usage, revealing an increase in damage to ground cover and soil exposure at Hemlock Overlook Regional Park and Sully Woodlands.⁴³

Edwards et al. (2016) observed a reduction in lone star ticks after 4-Poster deployment; however, there was also a decrease in lone star ticks in the respective control area.⁴³ The authors reported a low number of blacklegged tick populations, but no observed reduction was documented with 4-Poster deployment. Therefore, Edwards et al. (2016) conclude that the effectiveness of the 4-Poster devices on reducing tick populations was unclear.⁴³ Environmental damage, potential for disease spread, and deer population growth were their reasons for not implementing the 4-Poster device in the future.⁴³ Furthermore, they found that some acaricide rollers were not properly positioned, which could have reduced the effectiveness as deer may not have received the permethrin solution while feeding. Deer with pink ears (marked from the dye in the rollers) and without pink ears were both noted to have ticks. The authors noted that dye was only applied to the rollers in the beginning of the season, so it is unknown whether unmarked deer didn't use the feeders, didn't touch the

rollers when using the feeders, or did touch the rollers at a time when no dye was present, but the permethrin solution was.⁴³ Furthermore, they note that it is possible that pink-eared deer used the posters when only dye, not acaricide, was applied, further complicating the interpretation of the results.⁴³ The study did not recommend continued implementation of the intervention. They concluded that in order to reduce tick populations, manage wildlife, and address environmental issues, an integrated approach is needed.^{43, 45, 46}

Effectiveness Summary

Based on the four key studies outlined above, 4-Poster devices only appear to be a moderately effective evidence-based intervention for reducing tick populations when maintained in certain parameters. Studies have discussed the potential consequences of 4-Poster operation, such as damage to soil cover and the environment, the possibility of disease transmission due to congregation of deer and non-target wildlife species to one feeding area, and the potential contribution of 4-Poster devices to deer population growth. Concerns are present regarding the effects of 4-Poster operation on the incidence of tick-borne disease. For Lyme disease, long-term studies with continual 4-Poster operation would be necessary to examine the 4-Poster effectiveness for reducing incidence of tick-borne disease. While questions still remain and additional research is required, tick populations may be moderately reduced through 4-Poster interventions under certain parameters, such as deployment in enclosed areas with high device density over a short period of time, as part of a larger integrated tick management strategy.

Implementation

If, given the shortcomings listed above, communities decide to pursue the use of 4-Poster devices in collaboration with other relevant agencies and partners, the information below will help with planning deployment and potentially improving the effectiveness of the intervention.

Logistics

Implementation of the 4-Poster deer self-treatment device requires a number of personnel and resources. A health department may or may not be the lead agency directing the use of this intervention. Decisions should be made on a local level with support from health department(s), department(s) of natural resources, department(s) of agriculture, fish and game agencies, local community groups and land owners, and other relevant stakeholders in the jurisdictions that are considering them. Together, these organizations and agencies can assess the appropriateness of the intervention strategy, identify areas of high tick abundance and reported tick-borne disease, and determine whether the parameters of the site are conducive to implementation given the available resources. Before deployment, agencies should be aware of the required permits and regulations surrounding 4-Poster device operation including but not limited to interventions to wildlife populations, feeding bans, and required licensure and permits for handling chemical substances.

The Y-TEX Corporation 10% permethrin Tickicide label states deployment of 4-Poster devices should be further than 100 yards from residential communities, playgrounds, or any place where children may be present.^{42, 47, 48, 49} In situations where 4-Poster devices must be placed within 100 yards of residential communities, however, precautionary signs and a 28–30 inch-high fence need to be positioned around the 4-Poster bait stations with a minimum of a 14.5 foot radius to prevent restricted personnel from coming into contact with the device.^{42, 49} Other rules and regulations, such as prohibitions on deer or animal feeding, should be ascertained and followed. For example, New York State law restricts the feeding of deer and moose in response to threats of CWD.⁵⁰

Agencies and organizations can purchase re-cleaned, whole kernel corn (“deer corn” or “feed corn”) as bait to attract white-tailed deer to the 4-Poster stations. Devices are often baited with 250 pounds of corn.⁴² The number of 4-Poster devices purchased is based on the size of the treatment area, following the recommendation of one 4-Poster device for every 21 hectares, or one device per every 40 acres.^{41, 42} Agencies and entities will need to purchase fibrous paint roller replacements, applicator guns, personal protective equipment (PPE), and pour-on acaricide. Since PointGuard (2% amitraz oily pour-on formulation) acaricide is no longer sold, the Environmental Protection Agency (EPA) permits the use of a 10% oily permethrin formulation by Y-TEX (Cody, WY).^{41, 43, 51} The 10% permethrin/Tickicide solution should be applied at a rate of 1 mL (0.25 mL per post) per 1.5 pounds of corn consumed. Health departments and other agencies and entities operating the 4-Poster devices also need to employ licensed personnel to operate and maintain the devices, and handle the permethrin solution.

Agencies should deploy 4-Poster bait stations during peak tick seasons. For example, in Massachusetts, 4-Poster devices were deployed during seasons of high tick activity—in the fall from mid-August to mid-November, and in the spring from mid-March to mid-June for targeting blacklegged ticks.⁴¹ Due to regional variations in climate, health departments and other agencies and entities should deploy 4-Poster devices during tick feeding seasons of the targeted tick species.

Feasibility

The expenses for maintaining the four 4-Poster devices in the Solberg et al. (2003) study varied yearly. In 1995, prices for estimated supplied corn and permethrin and estimated costs for labor were \$7,064; for 1996, \$17,859; for 1997, \$12,742; for 1998, \$9,964.35. Prices for corn were based on average corn costs. The inclusion of costs for 4-Posters, replacement rollers, applicator guns, hood, personal protective equipment, incidentals, and precautionary signs were not indicated in the estimated yearly costs, indicating that true cost of implementation could be much greater than stated in the study. Additionally, the prices for materials, labor, and 4-Poster deployment and maintenance are likely to have increased since the 1990s.

The costs for implementing the 4-Poster self-treatment devices in Fairfax County from 2012 to 2015 revealed an average annual expense of \$47,030 for the operation and maintenance of twenty 4-Poster bait stations, which includes the expenses for corn, permethrin, and labor for one staff member.⁴³ The cost, however, did not include the

price for replacement rollers, applicator guns, hood, personal protective equipment, incidentals, and precautionary signs.

The expenses calculated by Edwards et al. (2016) and Solberg et al. (2003) were computed based on prices in each respective jurisdiction. Total cost may vary by location. Additionally, health departments and other organizations should consider that the costs to deploy the treatment devices are dependent on the number of 4-Posters, size of the treatment area, deer population, frequency in which 4-Posters are recharged with permethrin and corn bait, abundance of non-target wildlife species utilizing the 4-Poster, length of deployment, and the number of personnel required to maintain the device.⁴¹

Worker Safety and Pesticide Exposure

To ensure worker safety and health, all persons who are in contact with the 10% permethrin insecticide should be cautious when handling the substance to minimize risk of exposure. Personnel handling the permethrin solution should be licensed applicators.⁵² Per the Occupational Safety and Health Administration's Hazard Communication Standard Classification and in accordance with the Safety Data Sheet, 10% permethrin is a suspected carcinogen that is harmful if swallowed or inhaled, and may cause eye and skin irritations or allergic skin reactions.^{47, 53} Workers should be cognizant of the hazards involved with utilizing 10% permethrin and follow precautions before, during, and after handling the product. Personnel should comply with the directions listed on the product's label.

Workers should adhere to the following precautions and protective measures when working with 10% permethrin.^{47, 53, 54}

1. Use product only outdoors or in a well-ventilated area.
2. Wear long-sleeve shirts, long pants, chemical-resistant gloves, shoes, and socks.
3. Avoid breathing mist, vapors, and spray. Although respirators are not required, personnel may use NIOSH-approved P-class filtering face pieces and respirators to minimize risk of inhalation.
4. Wash hands thoroughly after handling the product and before eating, drinking, toileting, or smoking. Do not eat, drink, or smoke when using the product.
5. Avoid dermal contact, damaging the container, and cross contamination.
6. Store the product in a cool, well-ventilated place. Store upright at room temperature and avoid exposure to extreme temperatures. Do not store near heat or an open flame, and store away from food, feed, or children.
7. Obtain special instructions before use. Do not handle until all safety precautions, user safety recommendations, and first aid measures have been read and understood.

In addition to precautionary and protective measures, workers should be familiar with the emergency procedures and exposure protocol. The following are recommendations for first aid measures and processes in the event of an emergency.^{47, 53, 54}

HAZARD/EXPOSURE	FIRST AID MEASURE
Ingested:	Rinse mouth. Call a poison control center for advice.
Eyes:	Rinse eye gently with water for 15–20 minutes. If applicable and easy to do, remove contact lenses. Continue rinsing eye. Should eye irritation persist, seek medical advice.
Skin:	Wash with plenty of water and soap for 15–20 minutes. If skin irritation occurs, seek medical advice.
Clothing:	Remove contaminated clothing and wash before reuse. Contaminated work clothing must not be allowed out of the workplace.
Inhaled:	Remove the person to fresh air. If the person is not breathing, call 911 or an ambulance, then give artificial respiration, preferably by mouth-to-mouth, if possible. Call a poison control center for medical advice.

EMERGENCY/DISPOSAL	PROTOCOL
Pesticide fire:	Isolate the fire area, evacuate downwind. Refrain from breathing gases, smokes, or vapors. Wear self-contained breathing apparatus and full-protective clothing, and cool fire-exposed areas and equipment.
Disposal:	Dispose of excess or waste pesticide by use according to label directions, or contact your State Pesticide or Environmental Control Agency, or the Hazardous Waste representative at the nearest EPA Regional Office for guidance. Improper disposal of pesticides is a violation of Federal Law. Containers should be disposed of according to label instructions and local, state, and federal health and environmental regulations.

Acaricide spillage

Operators should adhere to instructions on the label and safety data sheet of the acaricide, avoiding any spillage or runoff from the 4-Poster device to prevent environmental contamination. According to the safety data sheet of 10% permethrin, any contamination into municipal wastewater, public storm drains, fish ponds, streams, lakes, rivers, or other water sources should be avoided.⁵³ For example, 4-Posters should not be deployed in or near vulnerable habitats such as wetlands, where the acaricide may runoff into bodies of water. In the event where spillage does occur, operators should respond according to the instructions on the label and safety data sheet. Pound et al. (2009) reported the presence of acaricide spillage of 2% amitraz in the NEATCP studies due to a loose hose, leaks from the hood, and over-charged rollers.⁴¹ To prevent spillage to the environment, Pound et al. (2009) reported the tightening of the hose and the use of catch pans to collect drips from over-charged rollers.⁴¹

Acaricide resistance

Although 10% permethrin is the acaricide currently registered for use with 4-Poster deployment,⁴³ the topic of acaricide resistance is important to consider when controlling tick populations.⁵⁵ As previously mentioned, Solberg et al. (2003) recommended future 4-Poster operators to alternate acaricides to prevent permethrin

resistance in ticks.³⁵ Eiden, Kaufman, Oi, Allan, and Miller (2015) observed permethrin and fipronil resistance in a sample of brown dog ticks (*R. sanguineus*) collected from Florida and Texas.⁵⁶ Resistance was presumed to be due to many factors related to flea and tick treatment for domestic animals, including lack of rotation of products used, utilization of different products with the same active ingredient, or treatment of pets with a low-dose exposure that was not sufficient for tick control.⁵⁶ Similar to the ticks' developed resistance against permethrin and fipronil, the deployment of 4-Poster devices with permethrin may also have the potential for developing localized resistance to permethrin among tick populations where 4-Posters are deployed.

Pesticide exposure in deer and other non-target species

Permethrin belongs to a group of chemicals called pyrethroids. The Agency for Toxic Substances and Disease Registry (ATSDR) states that pyrethroids rapidly metabolize in the environment by sunlight or other atmospheric compounds.⁵⁷ The swift dissipation of permethrin, and its route of transfer through topical application, makes it safe for deer and other non-target species.^{57, 58} If the 4-Poster bait station employed permethrin through the route of oral ingestion, however, the EPA states permethrin would likely be carcinogenic to both humans and mammals.^{43, 57} According to the ATSDR, permethrin is extremely toxic to fish;⁵⁷ therefore, personnel handling the permethrin solution should follow protocol to prevent exposure to fish through streams, lakes, ponds, or rivers.

Pesticide exposure through human consumption of deer

The utilization of permethrin on deer through 4-Poster deployment may draw concern among hunters; however, the U.S. Food and Drug Administration (FDA) and the EPA affirm the safety of venison for human consumption, despite 4-Poster treatment.^{43, 58} Due to the topical application of permethrin, deer treated by 4-Poster bait stations are deemed safe for human consumption. The rapid metabolism rate of permethrin, in addition to its topical application method, makes it challenging for the chemical to be absorbed.^{43, 57, 58}

Other considerations

Prior to 4-Poster device deployment, agencies should ascertain if there are any state regulations prohibiting deer feeding.⁵⁹ Additionally, any regulations on feeding of other animals should be followed. Edwards et al. (2016) observed bear activity during 4-Poster deployment in Virginia, in which the deliberate or unintentional feeding of bears is illegal.⁴³ Electric bear exclusion fences were implemented to prevent bears from reaching the 4-Poster sites,⁴³ which represents an additional cost associated with 4-Poster usage. Furthermore, implementation of 4-Poster devices utilizing permethrin should comply with any restrictions relating to proximity of deployment of 4-Posters with permethrin near residential areas.⁴⁷ If 4-Poster devices plan to be operated near residential communities, workers should solicit residents or property owners for participation and permission.⁵⁹ Additionally, when identifying a treatment area, health departments and stakeholders should select an area that is farther from roads to prevent deer-vehicle collisions.⁴⁷ Personnel operating and maintaining the 4-Poster device should be cognizant of any illegal usage by hunters or poachers.⁴⁷

If no other rules or regulations exist and health departments follow the previous steps to implement the 4-Poster intervention, personnel should consider the following recommendations from the literature to improve 4-Poster effectiveness.

Reduction of use by non-target species

In previous studies evaluating the effectiveness of the 4-Poster device, researchers deployed trail cameras which revealed usage of the bait station by non-target wildlife species such as gray squirrels, woodchucks, raccoons, crows, wild hogs, grey foxes, and turkeys.^{39, 41} Utilization of the 4-Poster applicator by non-target species contributes to excess expenditures relating to bait maintenance necessary for continued 4-Poster activity. For example, gray squirrels, according to Carroll, Pound, Miller, and Kramer (2008), were significant contributors to corn blockages by leaving partially consumed corn fragments and dust in the lateral feeding bins.⁶⁰ The accrual of broken corn kernels, cob fragments, and dust has been shown to reduce 4-Poster effectiveness.⁴¹ The corn blockages, when combined with saliva, create an ideal environment for mold growth. Precipitation could also promote blockage or mold growth. Additionally, Harmon et al. (2003) observed damage to 4-Posters by feral hogs.³⁹ Four-poster activity by non-target wildlife species increases the frequency of maintenance,^{39, 41} which increases costs to maintain 4-Poster devices.

To address these concerns, Carroll et al. (2008) implemented a photo sensor-controlled mechanism, which would restrict diurnal gray squirrels from feeding from the 4-Poster device. The apparatus was discovered to be effective in minimizing the risk of reduced effectiveness due to corn blockages; however, the device was not effective in preventing nocturnal non-target wildlife species from utilizing the 4-Poster device. Carroll et al. (2008) concluded the mechanism would be more effective in areas with low abundance of deer and dense gray squirrel populations;⁶⁰ however, areas such as these would likely not require the use of 4-Poster devices. Additionally, the deployment of photo sensor-controlled mechanisms would result in the additional accrual of expenses for tick mitigation. Health departments and other collaborative agencies should evaluate the density of target and non-target species in the treatment area to determine if this timed-release mechanism needs to be implemented with the 4-Poster device.

Spread of communicable diseases through congregation of deer and non-target species

As previously mentioned, there have been several concerns in the literature regarding the potential transmission of disease due to the congregation of deer and other non-target species to one feeding station. Additionally, the deployment of several bait stations has high potential to create other human wildlife conflicts and has the potential for disease to spread between and among wildlife species. It is important to consider the effect that baiting devices may have on population growth for all target and non-target species utilizing the devices, as they may be vectors for disease transmission. Several states have already banned baiting due to disease transmission from deer-baiting devices. One example was Michigan, who enforced a mandated ban on feeding wild deer to prevent the spread of bovine tuberculosis.⁶¹

In New York, moose and deer feeding were banned to prevent the spread of CWD.⁵⁰ Although the transmission of CWD is not completely understood, probable transmission is attributed to direct contact or contact with food waste, urine, and feces at feeding sites.^{50, 62} The presence of CWD or other communicable diseases would require 4-Poster removal; however, operators should follow removal guidelines of deer feeders per state regulations. For example, in Wisconsin, counties permitting deer feeding and baiting may be banned in the event of CWD or bovine tuberculosis confirmation in the county, or if the county is in a 10-mile radius of an animal confirmed with CWD or bovine tuberculosis.⁶³

Another issue with 4-Poster bait stations concerns the communicability of the rabies virus among species using the 4-Poster device, and potentially to humans. The spread of rabies most commonly occurs through the bite and spread of virus-containing saliva from an infected host.⁶⁴ While all mammals are prone to infection by the rabies virus, significant rabies reservoirs in the U.S. are skunks, foxes, raccoons, and bats.⁶⁴ Studies have observed 4-Poster usage by non-target species such as raccoons, gray squirrels, crows, woodchucks, wild hogs, black bears, red and grey foxes, groundhogs, opossums, geese, and turkeys.^{35, 39, 41, 43} The presence of important rabies vector species (such as raccoons and foxes) at 4-Poster devices demonstrates the potential for rabies transmission between and among various wildlife species. This presents a concern in the effectiveness of 4-Poster devices.

Health departments, agencies, and stakeholders should consider the potential transmission of disease with 4-Poster implementation and adhere to protocol in the presence of communicable diseases, including CWD, bovine tuberculosis, or rabies transmission. Employment of surveillance methods would be necessary to monitor for CWD, rabies, and other communicable diseases that could transpire from 4-Poster usage.

Environmental factors—competing food sources

The consideration of environmental factors when deploying 4-Poster devices is also significant for successful tick control. Several studies were impacted by the presence of acorn masts during treatment periods.^{41, 65} Heavy acorn masts provided deer with an alternative food source, affecting 4-Poster effectiveness. Utilization of 4-Poster devices decreased during mast seasons, leading to implications such as reduced tick control. Stratified data analyzed by Pound et al. (2009) revealed a 20 percent decrease in 4-Poster device usage during mast periods.⁴¹ Since mast crops are highly variable on an annual basis and cannot be predicted, mast periods may impact the effectiveness of 4-Poster operation.

In addition to considering the impact of mast periods, agencies and organizations should consider surrounding habitat characteristics. Studies demonstrated reduced effectiveness of the 4-Poster bait station due to nearby fields of alfalfa and clover.^{41, 65} The presence of alternative food sources for deer has been shown in studies to diminish the effectiveness of the 4-Poster device.

Timing and seasonality

Considerations regarding the timing of 4-Poster deployment are significant for improving its effectiveness. One study utilizing 4-Posters in three locations in Maryland

darted and anesthetized deer to examine the presence of blacklegged adult ticks.⁴⁰ The researchers discussed arising issues when targeting blacklegged adult ticks. Blacklegged adult ticks are more active in the fall, winter, and early spring seasons when deer pelage is thicker. This thicker pelage may protect ticks from acaricide treatments.⁶⁰ To improve tick control, agencies should consider operating 4-Poster devices during seasons when tick activity is high.

Acclimatization to feeding at 4-Poster devices

In addition to considering the timing of 4-Poster deployment, the length of time necessary for deer to acclimatize to 4-Poster devices should be considered. Previous studies noticed usage of 4-Poster devices increase anywhere from a few weeks to one year following initial deployment.^{52, 65} Reports of initial low deer usage demonstrate that deer without previous experiences with 4-Poster devices require more time to acclimatize to the device.^{52, 65} To assist the deer with acclimation, studies utilized corn and apples on the ground to attract deer to the device prior to acaricide application.^{35, 66}

Deer population growth and environmental degradation

As previously mentioned, researchers have discussed concerns regarding the 4-Poster's effect on deer population growth. Residents near treatment areas had apprehensions towards 4-Poster devices, believing that the corn bait would encourage deer reproduction and survival.⁶⁷ Miller et al. (2009) observed a slight increase in deer populations in the treatment area; however, they also observed a threefold increase in the control area, suggesting that the supplied food source did not influence deer population growth.⁶⁵ Deer density also increased in both treatment areas in the study conducted by Edwards et al. (2016); however, the increase could not be attributed solely to 4-Poster devices.⁴³ Due to the indistinct relationship between 4-Posters and deer population growth, operators should still consider the possibility of 4-Poster devices contributing to a rise in deer populations.

An additional consideration with 4-Poster deployment is the impact it has on the environment. The gathering of deer at each bait station may lead to damage in ground cover and soil exposure, as experienced in Edwards et al. (2016).⁴³ Large numbers of deer can lead to damaged agricultural crops, forestry, and landscapes.⁶⁸ Edwards et al. (2016) observed severe levels of deer browse, which refers to the damage caused by deer as they feed on shrubs and plants.⁴³ Before 4-Poster initiation, it is important to consider the impacts 4-Poster deployment may have on the environment.

Vermont Tick Tracker

Vermont has one of the highest incidence rates of Lyme disease in the country. In the northeast, the spread of the lone star tick is of interest, given that populations of this important vector species are not currently known to be established in Vermont, but are present in nearby northeastern states.

Released in 2013, the Vermont Tick Tracker, a product of the state's Environmental Health Tracking Program, is a crowd-sourced tool that allows citizens to participate in the scientific process by reporting their own tick encounters (see Figure 8). This interactive resource allows users to report tick encounters, identify the tick species, and view where other tick encounters have happened throughout the state. The more reports posted by users, the better the information the tracker can provide. This gives valuable information on the timing and geographic distribution of tick activity in the state. This provides supplemental information to the active tick surveillance work conducted by the state and its academic partners. However, information from these types of crowd-sourced tools need to be interpreted with caution, as they can suffer from errors in tick identifications, and geographic bias due to heterogeneous population distributions. In spite of issues with data quality, these types of crowd-sourced tools can be valuable assets in educating the public about health issues, in this case, tick bite prevention.

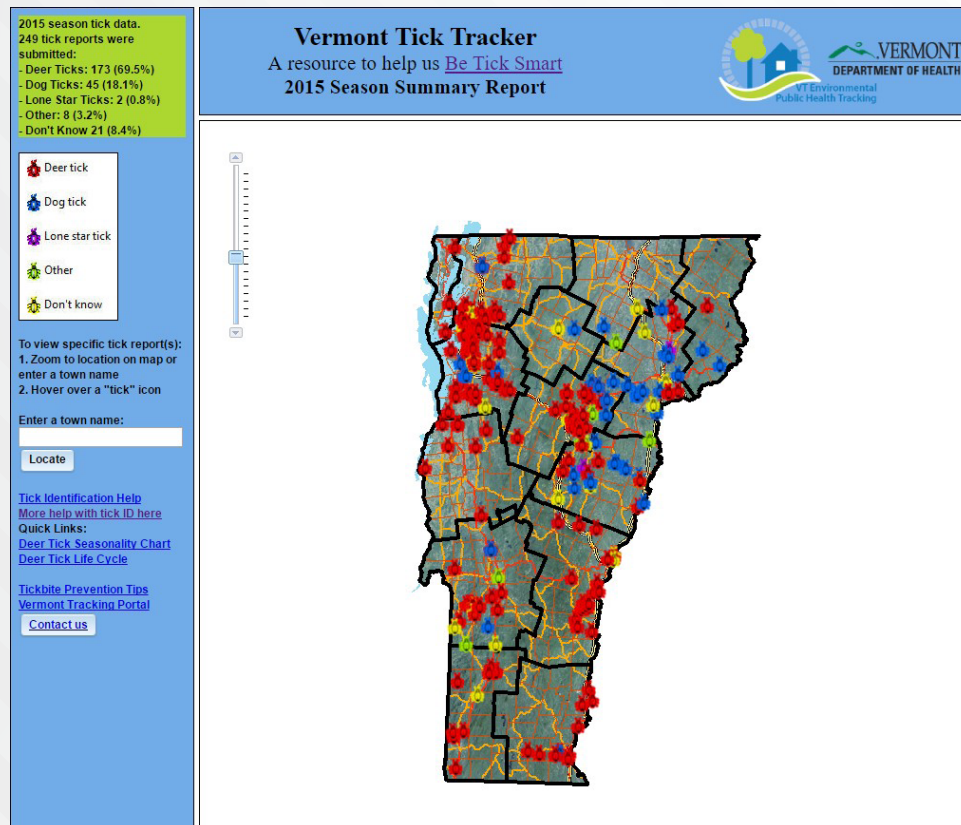


Figure 8. Vermont Tick Tracker—2015 Season Summary Report⁶⁹

Conclusion

The literature has demonstrated moderate support for the deployment of 4-Poster deer self-treatment bait stations for mitigating tick populations in certain limited situations when used as one part of an integrated tick management strategy. High effectiveness was only demonstrated in isolated areas of small spatial parameters with high deployment density. However, as soon as 4-Poster devices were removed, tick populations rebounded. Long-term maintenance costs and other considerations such as disease transmission, environmental damage, pesticide exposure, and restricted reliability limit the effectiveness of 4-Poster devices. Finally, more research is needed to demonstrate the impact of 4-Poster device operation for reducing tick-borne illness in humans.

As the changing climate influences tick populations, assessing potential interventions is an essential step in the CDC's BRACE framework for jurisdictions where tick control may be a priority. Ensuring effectiveness of existing public health prevention measures will help to prevent the emergence or re-emergence of tick-borne diseases.

Hypothetical Examples of Intervention Selection

Scenario A

A nature center in the Midwest has noticed an increasing abundance of ticks on their property. Recently a visitor hiking on one of the nature center's interpretive trails reported finding a tick on her leg. The nature center decides to consider strategies for preventing the potential spread of tick-borne disease among visitors.

The center has a large population of habituated white-tailed deer living inside a 3.5 square mile fenced-in facility. A series of hiking and nature trails loop through the property. A local University has produced downscaled ecological niche modeling that shows climatic conditions in the area will become more conducive to blacklegged ticks in the near future.

Nature center staff contacts their state department of natural resources, state department of health, and county health department to discuss options. Based on the nature of the site, they decide to explore the deployment of 4-Poster devices as part of a larger tick-control strategy including visitor education and the widening of forest trails to reduce visitor/tick contact. There are no bear, fox, hogs, or other similar animals on the property that could interfere with 4-Poster effectiveness (although the nature center staff note that squirrels and turkey are present and could be attracted to 4-Poster devices). There is no history of chronic wasting disease or terrestrial rabies transmission in the area. There are no residences within the bounds of the nature center. Devices could be located in forested areas not visible from hiking trails, where there is little chance of human contact. The state does not have a ban on feeding wildlife. The state has an existing integrated tick management program.

The nature center decides, in collaboration with multiple partners including the state health department, to implement 4-Poster devices as a means of controlling the increasing tick population on their property. Using funding awarded from the state's tick management program, the center oversees implementation of 4-Poster devices as one aspect of a multi-pronged intervention strategy.

Scenario B

A county health department in New England has seen increasing incidence of Lyme disease reported to their health surveillance network. Previously there had not been reported Lyme disease in the county. The health department decides to investigate options for preventing further spread of Lyme disease.

The county is 450 square miles, largely suburban and forested in nature, with a population of 165,000 people. Most people live in low-density single-family housing spread across the county, interspersed with forested areas. A large population of white tailed deer can easily move throughout the county and across county lines through forested areas, farmland, and residential neighborhoods. There is no history of chronic wasting disease in the area, and no state or local laws prohibit the feeding of deer. The state does not have an existing tick management strategy.

The county health department considers a number of strategies, and consults with county commissioners, the department of parks and recreation, the state health department's vector-borne disease program, and a local wildlife center. The health department concludes that the implementation of 4-Poster devices would likely be ineffective due to the large geographic area, the number of stations that would be needed, costs, high potential for human exposure, and potential public opposition in residential areas. They implement an educational campaign to encourage residents to search themselves and pets for ticks after being in tick-infected areas, and to use repellents with 20%-30% DEET or wear permethrin treated clothing. They focus this strategy on the April-September tick season and communicate through social media, the county health department website, and posted information at trailheads and county parks.

References

1. Johns Hopkins Bloomberg School of Public Health (JHSPH). (2015). Lyme disease costs up to \$1.3 billion per year to treat, study finds. *News*. Retrieved from <http://www.jhsph.edu/news/news-releases/2015/lyme-disease-costs-more-than-one-billion-dollars-per-year-to-treat-study-finds.html>
2. Walter, K.S., Pepin, K.M., Webb, C.T., Gaff, H.D., Krause, P.J., Pitzer, V.E., & Diuk-Wasser, M.A. (2016). Invasion of two tick-borne diseases across New England: Harnessing human surveillance data to capture underlying ecological invasion processes. *Proceedings of the Royal Society: Biological Sciences*, 283(1832). doi: 10.1098/rspb.2016.0834.
3. U.S. Global Change Research Program (USGCRP). (2016). Vector-borne diseases *Climate and Health Assessment*. Retrieved from <https://health2016.globalchange.gov/vectorborne-diseases>
4. Marinucci, G.D., Lubber, G., Uejio, C.K., Saha, S., & Hess, J.J. (2014). Building resilience against climate effects—A novel framework to facilitate climate readiness in public health agencies. *International Journal of Environmental Research and Public Health*, 11(6), 6433-6458. doi: 10.3390/ijerph110606433.
5. Centers for Disease Control and Prevention. (CDC). 2016. Tickborne diseases of the United States. *Ticks*. Retrieved from <http://www.cdc.gov/ticks/diseases/index.html>
6. Centers for Disease Control and Prevention. (CDC). 2015. Data and statistics. *Lyme disease*. Retrieved from <http://www.cdc.gov/lyme/stats>
7. Adrion, E.R., Aucott, J., Lemke, K.W., & Weiner, J.P. (2015). Health care costs, utilization and patterns of care following Lyme disease. *Public Library of Science (PLoS) One*, 10(2). doi: 10.1371/journal.pone.0116767.
8. Centers for Disease Control and Prevention. (CDC). (2015). Reported cases of Lyme disease – United States, 2001-2014 [Map]. Retrieved from <http://www.cdc.gov/lyme/stats/index.html>
9. Centers for Disease Control and Prevention. (CDC). (2015). Geographic distribution of ticks that bite humans. *Ticks*. Retrieved from http://www.cdc.gov/ticks/geographic_distribution.html
10. Centers for Disease Control and Prevention. (CDC). 2015. Life cycle of hard ticks that spread disease. *Ticks*. Retrieved from http://www.cdc.gov/ticks/life_cycle_and_hosts.html
11. University of California Davis. (2016). Department of Entomology and Nematology. Retrieved from http://entomology.ucdavis.edu/Faculty/Robert_B_Kimsey/Kimsey_Research/Tick_Biology/
12. Centers for Disease Control and Prevention. (CDC). (2015). Life cycle of blacklegged ticks that can transmit anaplasmosis, babesiosis, and Lyme disease [Diagram]. Retrieved from http://www.cdc.gov/ticks/life_cycle_and_hosts.html
13. Wilson, M.L., Adler, G.H., & Spielman, A. (1985). Correlation between abundance of deer and that of the deer tick, *Ixodes dammini* (Acari: Ixodidae). *Annals of the Entomological Society of America*, 78(2), 172-176.
14. Rand, P.W., Lubelczyk, C., Lavigne, G.R., Elias, S., Holman, M.S., Lacombe, E.H., & Smith Jr., R.P. (2003). Deer density and the abundance of *Ixodes scapularis* (Acari: Ixodidae). *Journal of Medical Entomology*, 40(2), 179-184.
15. Kilpatrick, H.J., LaBonte, A.M., & Stafford III, K.C. (2014). The relationship between deer density, tick abundance, and human cases of Lyme disease in a residential community. *Journal of Medical Entomology*, 51(4), 777-784. doi: 10.1603/ME13232.
16. Stafford III, K.C., & Williams, S.C. (2014). Deer, ticks, and Lyme disease: Deer management as a strategy for the reduction of Lyme disease. *The Connecticut Agricultural Experiment Station*. Retrieved from http://www.ct.gov/caes/lib/caes/documents/publications/fact_sheets/entomology/deer_&_ticks_fact_sheet.pdf
17. U.S. Global Change Research Program (USGCRP). (2016). The impacts of climate change on human health in the United States: A scientific assessment. *Climate and Health Assessment*. Retrieved from <http://health2016.globalchange.gov>

18. Ogden, N.H., St-Onge, L., Barker, I.K., Brazeau, S., Bigras-Poulin, M., Charron, D.F.,...Thompson, R. (2008). Risk maps for range expansion of the Lyme Disease vector, *Ixodes scapularis*, in Canada now and with climate change. *International Journal of Health Geographics*, 7(24). doi: 10.1186/1476-072X-7-24.
19. Kurtenbach, K., Hanincova, K., Tsao, J.I., Margos, G., Fish, D., & Ogden, N.H. (2006). Fundamental processes in the evolutionary ecology of Lyme borreliosis. *Nature Reviews Microbiology*, 4, 660-669. doi: 10.1038/nrmicro1475.
20. Ogden, N.H., Maarouf, A., Barker, I.K., Bigras-Poulin, M., Lindsay, L.R., Morshed, M.G.,...Charron, D.F. (2005). Climate change and the potential for range expansion of the Lyme disease vector *Ixodes scapularis* in Canada. *International Journal for Parasitology*, 36(1), 63-70. doi: 10.1016/j.ijpara.2005.08.016.
21. Moore, S.M., Eisen, R.J., Monaghan, A., & Mead, P. (2014). Meteorological influences on the seasonality of Lyme Disease in the United States. *The American Journal of Tropical Medicine and Hygiene*, 90(3), 486-496. doi: 10.4269/ajtmh.13-0180.
22. Eisen, L., & Eisen, R.J. (2016). Critical evaluation of the linkage between tick-based risk measures and the occurrence of Lyme disease cases. *Journal of Medical Entomology*, 53(6), 1-13. doi: 10.1093/jme/tjw092.
23. Medlock, J.M., Hansford, K.M., Bormane, A., Derdakova, M., Estrada-Pena, A., George, J.C.,...Van Bortel, W. (2013). Driving forces for changes in geographical distribution of *Ixodes ricinus* ticks in Europe. *Parasites and vectors*, 6(1), 1-11. doi: 10.1186/17563305-6-1.
24. Githeko, A.K., Lindsay, S.W., Confalonieri, U.E., & Patz, J.A. (2000). Climate change and vector-borne diseases: A regional analysis. *Bulletin of the World Health Organization*, 78(9), 1136-1147. Retrieved from <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2560843/pdf/11019462.pdf>
25. Hahn, M.B., Jarnevich, C.S., Monaghan, A.J., & Eisen, R.J. (2016). Modeling the geographic distribution of *Ixodes scapularis* and *Ixodes pacificus* (Acari: Ixodidae) in the contiguous United States. *Journal of Medical Entomology* (Epub ahead of print), 1-16. doi: 10.1093/jme/tjw076.
26. Ostfeld, R.S., Brunner, J.L. (2015). Climate change and *Ixodes* tick-borne disease of humans. *Philosophical Transactions of the Royal Society B*, 370. doi: 10.1098/rstb.2014.0051.
27. Dolan, M.C., Jordan, R.A., Schulze, T.L., Schulze, C.J., Manning, M.C., Ruffolo, D.,...Karchesy, J.J. (2009). Ability of two natural products, nootkatone and carvacrol, to suppress *Ixodes scapularis* and *Amblyomma americanum* (Acari: Ixodidae) in a Lyme disease endemic area of New Jersey. *Journal of Economic Entomology*, 102(6), 2316-2324. Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/20069863>
28. Jordan, R.A., Dolan, M.C., Piesman, J., & Schulze, T.L. (2011). Suppression of host-seeking *Ixodes scapularis* and *Amblyomma americanum* (Acari: Ixodidae) nymphs after dual applications of plant-derived acaricides in New Jersey. *Journal of Economic Entomology*, 104(2), 659-664. doi: 10.1603/EC10340.
29. Hinckley, A.F., Meek, J.I., Ray, J.A., Niesobecki, S.A., Connally, N.P., Feldman, K.A.,...Mead, P.S. (2016). Effectiveness of residential acaricides to prevent Lyme and other tick-borne diseases in humans. *Journal of Infectious Diseases*, 214(2), 182-188. doi: 10.1093/infdis/jiv775.
30. Vaughn, M.F., Funkhouser, S.W., Lin, F.C., Fine, J., Juliano, J.J., Apperson, C.S., & Meshnick, S.R. (2014). Long-lasting permethrin impregnated uniforms: A randomized-controlled trial for tick bite prevention. *American Journal of Preventive Medicine*, 46(5), 473-480. doi: 10.1016/j.amepre.2014.01.008.
31. Vaughn, M.F., & Meshnick, S.R. (2011). Pilot study assessing the effectiveness of long-lasting permethrin-impregnated clothing for the prevention of tick bites. *Vector Borne Zoonotic Diseases*, 11(7), 869-875. doi: 10.1089/vbz.2010.0158.
32. Evans, S.R., Korch Jr, G.W., & Lawson, M.A. (1990). Comparative field evaluation of permethrin and deet-treated military uniforms for personal protection against ticks (Acari). *Journal of Medical Entomology*, 27(5), 829-834. Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/2231620>
33. Daltroy, L.H., Phillips, C., Lew, R., Wright, E., Shadick, N.A., & Liang, M.H. (2007). A controlled trial of a novel primary prevention program for Lyme disease and other tick-borne illnesses. *Health Education and Behavior*, 34(3), 531-542. doi: 10.1177/1090198106294646.

34. Malouin, R., Winch, P., Leontsini, E., Glass, G., Simon, D., Hayes, E.B., & Schwartz, B.S. (2003). Longitudinal evaluation of an educational intervention for preventing tick bites in an area with endemic Lyme disease in Baltimore County, Maryland. *American Journal of Epidemiology*, 157(11), 1039-1051. doi: 10.1093/aje/kwg076.
35. Solberg, V.B., Miller, J.A., Hadfield, T., Burge, R., Schech, J.M., & Pound, J.M. (2003). Control of *Ixodes scapularis* (Acari: Ixodidae) with topical self-application of permethrin by white-tailed deer inhabiting NASA, Beltsville, Maryland. *Journal of Vector Ecology*, 28(1), 117-134. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/12831136>
36. Pound, J.M., Miller, J.A., George, J.E., & Lemeilleur, C.A. (2000). The '4-poster' passive topical treatment device to apply acaricide for controlling ticks (Acari: Ixodidae) feeding on white-tailed deer. *Journal of Medical Entomology*, 37(4), 588-594. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/10916301>
37. United States Department of Agriculture. (USDA). (2008). 4-poster bait station [Photograph]. Retrieved from <http://www.ars.usda.gov/is/kids/insects/story19/3tick.htm>
38. Ryan, W. (2006). A buck feeds from a plastic 4-poster [Photograph]. Retrieved from <http://www.ars.usda.gov/is/graphics/photos/jun06/d513-1.htm>
39. Harmon, J.R., Hickling, G.J., Scott, M.C., & Jones, C.J. (2011). Evaluation of 4-poster acaricide applicators to manage tick populations associated with disease risk in a Tennessee retirement community. *Journal of Vector Ecology: Journal of the Society for Vector Ecology*, 36(2), 404-410. doi: 10.1111/j.1948-7134.2011.00181.x.
40. Gear, J.S., Koethe, R., Hoskins, B., Hillger, R., Dapsis, L., & Pongsiri, M. (2014). The effectiveness of permethrin-treated deer stations for control of the Lyme Disease vector *Ixodes scapularis* on Cape Cod and the islands: A five-year experiment. *Parasites and Vectors*, 7, 292. doi: 10.1186/1756-3305-7-292.
41. Pound, J.M., Miller, J.A., George, J.E., Fish, D., Carroll, J.F., Schulze, T.L.,...Mather, T.N. (2009). The United States Department of Agriculture's Northeast area-wide tick control project: Summary and conclusions. *Vector Borne and Zoonotic Diseases*, 9(4), 439-448. doi: 10.1089/vbz.2008.0200.
42. Kelly Solutions. (2011). Y-TEX 4-poster tickicide. Retrieved from [http://www.kellysolutions.com/erenewals/documentssubmit/KellyData/NE/pesticide/Product Label/39039/39039-12/39039-12_4_POSTER_TICKICIDE_7_27_2011_10_47_39_AM.pdf](http://www.kellysolutions.com/erenewals/documentssubmit/KellyData/NE/pesticide/Product%20Label/39039/39039-12/39039-12_4_POSTER_TICKICIDE_7_27_2011_10_47_39_AM.pdf)
43. Edwards, K.E., Smith, J., Bankert, C.A., Auer, K.M., Everitts, J.L., O'Donnell, A.W.,...Arias, J.R. (2016). A study report on the use of 4-poster deer treatment stations to control tick infestations on white-tailed deer (*Odocoileus virginianus*) in Fairfax County, Virginia. *Fairfax County Police Department and Fairfax County Health Department*. Retrieved from <http://www.fairfaxcounty.gov/living/wildlife/pilotstudy/4-poster.htm>
44. Schulze, T.L., Jordan, R.A., & Dolan, M.C. (2011) Experimental use of two standard tick collection methods to evaluate the relative effectiveness of several plant-derived and synthetic repellents against *Ixodes scapularis* and *Amblyomma americanum* (Acari: Ixodidae). *Journal of Economic Entomology*, 104(6), 2062-2067. doi:10.1603/EC10421.
45. Carroll, J.F., Allen, P.C., Hill, D.E., Pound, J.M., Miller, J.A., & George, J.E. (2002). Control of *Ixodes scapularis* and *Amblyomma americanum* through use of the '4-poster' treatment device on deer in Maryland. *Experimental and Applied Acarology*, 28, 289-296. doi: 10.1023/a:1025383408163.
46. Childs, J.E. (2009). Low tech versus high tech approaches for vector-borne disease control. *Vector Borne Zoonotic Diseases*, 9(4), 355-356. doi: 10.1089/vbz.2009.9.4.0001.
47. Kelly Solutions. (n.d.). Y-TEX corporation: Material safety data sheet. Retrieved from http://www.kellysolutions.com/erenewals/documentssubmit/KellyData/NE/pesticide/MSDS/39039/39039-12/39039-12_4_POSTER_TICKICIDE_12_10_2007_6_07_16_PM.pdf
48. Stafford III, K.C. (2007). Tick management handbook: An integrated guide for homeowners, pest control operators, and public health officials for the prevention of tick-associated disease. *The Connecticut Agricultural Experiment Station*. Retrieved from <http://www.ct.gov/caes/lib/caes/documents/publications/bulletins/b1010.pdf>

49. United States Environmental Protection Agency. (EPA). (2008). Amendment—Change distance of device plus supplemental label Y-TEX 4-poster Tickicide. Retrieved from https://www3.epa.gov/pesticides/chem_search/ppls/039039-00012-20080421.pdf
50. New York State Department of Environmental Conservation. (n.d.). Deer and moose feeding regulations. Retrieved from <http://www.dec.ny.gov/animals/7197.html>
51. United States Environmental Protection Agency. (EPA). (2016). Suspended, cancelled, and restricted pesticides. Retrieved from <http://nepis.epa.gov/Exe/ZyNET.exe/20011EoG.txt?ZyActionD=ZyDocument&Client=EPA&Index=1986%20Thru%201990&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&UseQField=&InTQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5CZYFILES%5CINDEX%20DATA%5C86THRU90%5CXTXT%5C00000015%5C20011EoG.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=3>
52. Schulze, T.L., Jordan, R.A., Hung, R.W., & Schulze, C.J. (2009). Effectiveness of the 4-poster passive topical treatment device in the control of *Ixodes scapularis* and *Amblyomma americanum* (Acari: Ixodidae) in New Jersey. *Vector Borne and Zoonotic Diseases*, 9(4), 389-400. doi: 10.1089/vbz.2008.0160.
53. Safety Data Sheet: Martin's Permethrin 10% Multi-Purpose Insecticide. (SDS). (n.d.). Retrieved from http://s3-us-west-1.amazonaws.com/www.agrian.com/pdfs/Martins_Permethrin1_10_MSDS.pdf
54. The National Institute for Occupational Safety and Health. (NIOSH). (2015). Permethrin. *Centers for Disease Control and Prevention (CDC)*. Retrieved from <http://www.cdc.gov/niosh/ipcsneng/neng0312.html>
55. Eisen, L., & Dolan, M.C. (2016). Evidence for personal protective measures to reduce human contact with blacklegged ticks and for environmentally based control methods to suppress host-seeking blacklegged ticks and reduce infection with Lyme disease spirochetes in tick vectors and rodent reservoirs. *Journal of Medical Entomology Advance Access*, 1-30. Retrieved from <http://jme.oxfordjournals.org/content/jmedent/early/2016/07/23/jme.tjw113.full.pdf>
56. Eiden, A.L., Kaufman, P.E., Oi, F.M., Allan, S.A., & Miller, R.J. (2015). Detection of permethrin resistance and fipronil tolerance in *Rhipicephalus sanguineus* (Acari: Ixodidae) in the United States. *Journal of Medical Entomology*, 52(3), 429-436. doi: 10.1093/tjv005.
57. Agency for Toxic Substances and Disease Registry. (ATSDR). (2015). Public health statement for pyrethrins and pyrethroids. *Centers for Disease Control and Prevention (CDC)*. Retrieved from <http://www.atsdr.cdc.gov/PHS/PHS.asp?id=785&tid=153>
58. United States Environmental Protection Agency. (EPA). (2009). Reregistration eligibility decision (RED) for permethrin. Retrieved from <https://archive.epa.gov/pesticides/reregistration/web/pdf/permethrin-red-revised-may2009.pdf>
59. Schulze, T.L., Jordan, R.A., Schulze, C.J., Healy, S.P., Jahn, M.B., & Piesman, J. (2007). Integrated use of 4-poster passive topical treatment devices for deer, targeted acaricide applications, and Maxforce TMS bait boxes to rapidly suppress populations of *Ixodes scapularis* (Acari: Ixodidae) in a residential landscape. *Journal of Medical Entomology*, 44(5), 830-839. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/17915516>
60. Carroll, J.F., Pound, J.M., Miller, J.A., & Kramer, M. (2008). Reduced interference by gray squirrels with 4-poster deer treatment bait stations by using timed-release bait. *Journal of Vector Ecology: Journal of the Society for Vector Ecology*, 33(2), 325-332. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/19263853>
61. Michigan.gov. (2016). Governor's directive on Bovine TB eradication Governor's Office press release. *Michigan Emerging Disease Issues*. Retrieved from http://www.michigan.gov/emergingdiseases/0,4579,7-186-25804_26354_26647-80366--,00.html
62. Centers for Disease Control and Prevention [CDC]. (2015) Chronic wasting disease. Retrieved from <http://www.cdc.gov/prions/cwd/transmission.html>
63. Wisconsin deer baiting and wildlife feeding regulations. (n.d.). *Wisconsin Department of Natural Resources*. Retrieved from <http://www.dnr.wi.gov/files/pdf/pubs/wm/wm0456.pdf>

64. Centers for Disease Control and Prevention. (CDC). (2016). Wildlife reservoirs for rabies. Retrieved from http://www.cdc.gov/rabies/exposure/animals/wildlife_reservoirs.html
65. Miller, N.J., Thomas, W.A., & Mather, T.N. (2009). Evaluating a deer-targeted acaricide applicator for area-wide suppression of blacklegged ticks, *Ixodes scapularis* (Acari: Ixodidae), in Rhode Island. *Vector Borne and Zoonotic Diseases*, 9(4), 401-406. doi: 10.1089/vbz.2008.0164.
66. Stafford III, K.C., Denicola, A.J., Pound, J.M., Miller, J.A., & George, J.E. (2009). Topical treatment of white-tailed deer with an acaricide for the control of *Ixodes scapularis* (Acari: Ixodidae) in a Connecticut Lyme borreliosis hyperendemic community. *Vector Borne and Zoonotic Diseases*, 9(4), 371-379. doi: 10.1089/vbz.2008.0161.
67. Daniels, T.J., Falco, R.C., McHugh, E.E., Vellozzi, J., Boccia, T., Denicola, A.J.,...Fish, D. (2009). Acaricidal treatment of white-tailed deer to control *Ixodes scapularis* (Acari: Ixodidae) in a New York Lyme disease-endemic community. *Vector Borne and Zoonotic Diseases*, 9(4), 381-387. doi: 10.1089/vbz.2008.0197.
68. Indiana Department of Natural Resources. (n.d.). Managing deer damage. Retrieved from <http://www.in.gov/dnr/fshwild/2718.htm>
69. Vermont Tick Tracker. (2015). *U.S. Climate Resilience Toolkit*. Retrieved from <https://toolkit.climate.gov/tool/vermont-tick-tracker>

Appendix

PERCENT REDUCTION OF LARVAL TICKS IN THE LITERATURE USING THE 4-POSTER BAIT STATION AND PERMETHRIN

Author(s)	Location	Type	Acaricide	Length of Deployment	Device Density	Evaluation Time	% Reduction in Treatment Sites (blacklegged ticks)	% Reduction in Treatment Sites (lonestar ticks)
Solberg et al. (2003)	Maryland	Goddard Space Flight Center, NASA, and Patuxent Wildlife Research Center	10% permethrin	1995-1998	1/63 ha	1996		
						1997		
						1998		
Harmon et al. (2011)	Tennessee	Retirement community in Tennessee	10% permethrin	not clear	1/657 ha	not clear	90.1%*	
Grear et al. (2014)	Massachusetts	Cape Cod, Martha's Vineyard, Nantucket	10% permethrin	2007-2012	1/60 ha	not clear	not clear	not clear
Edwards et al. (2016)	Virginia	Hemlock Overlook Regional Park and Sully Woodlands	10% permethrin	2012-2015	1/20-25 ha	not clear	not clear	not clear

*Only when within 300 meters from the 4-Poster device

Table A1: Percent Reduction of Larval Ticks in the Literature Using the 4-Poster Bait Station and Permethrin

PERCENT REDUCTION OF NYMPHAL TICKS IN THE LITERATURE USING THE 4-POSTER BAIT STATION AND PERMETHRIN									
Author(s)	Location	Type	Acaricide	Length of Deployment	Device Density	Evaluation Time	% Reduction in Treatment Sites (blacklegged ticks)	% Reduction in Treatment Sites (lonestar ticks)	
Solberg et al. (2003)	Maryland	Goddard Space Flight Center, NASA, and Patuxent Wildlife Research Center	10% permethrin	1995-1998	1/63 ha	1996	100%		
						1997	100%		
						1998	100%		
Harmon et al. (2011)	Tennessee	Retirement community in Tennessee	10% permethrin	not clear	1/657 ha	not clear		68%*	
Gear et al. (2014)	Massachusetts	Cape Cod, Martha's Vineyard, Nantucket	10% permethrin	2007-2012	1/60 ha	not clear	8%		
Edwards et al. (2016)	Virginia	Hemlock Overlook Regional Park and Sully Woodlands	10% permethrin	2012-2015	1/20-25 ha	not clear	not clear	not clear	

*Only when within 300 meters from the 4-Poster device

Table A2: Percent Reduction of Nymphal Ticks in the Literature Using the 4-Poster Bait Station and Permethrin

PERCENT REDUCTION OF ADULT TICKS IN THE LITERATURE USING THE 4-POSTER BAIT STATION AND PERMETHRIN										
Author(s)	Location	Type	Acaricide	Length of Deployment	Device Density	Evaluation Time	% Reduction in Treatment Sites (blacklegged ticks)	% Reduction in Treatment Sites (lonestar ticks)		
Solberg et al. (2003)	Maryland	Goddard Space Flight Center, NASA, and Patuxent Wildlife Research Center	10% permethrin	1995-1998	1/63 ha	1996	78%			
						1997	100%			
						1998	100%			
Harmon et al. (2011)	Tennessee	Retirement community in Tennessee	10% permethrin	not clear	1/657 ha	not clear		49%*		
Gear et al. (2014)	Massachusetts	Cape Cod, Martha's Vineyard, Nantucket	10% permethrin	2007-2012	1/60 ha	not clear	8%			
Edwards et al. (2016)	Virginia	Hemlock Overlook Regional Park and Sully Woodlands	10% permethrin	2012-2015	1/20-25 ha	not clear	not clear			
							not clear			

*Only when within 300 meters from the 4-Poster device

Table A3: Percent Reduction of Adult Ticks in the Literature Using the 4-Poster Bait Station and Permethrin

