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Author manuscript
Zoonoses Public Health. Author manuscript; available in PMC 2024 February 27.

Published in final edited form as:
Zoonoses Public Health. 2021 September ; 68(6): 578–587. doi:10.1111/zph.12844.

Prevention of Lyme and other tickborne diseases using a rodent-targeted approach: A randomized controlled trial in Connecticut

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Summary

Tickborne diseases are an increasing public health problem in the northeastern USA. Bait boxes that apply acaricide to rodents have been shown in small field studies to significantly reduce abundance of *Ixodes scapularis* ticks as well as their pathogen infection rates in treated areas. The effectiveness of this intervention for preventing human tickborne diseases (TBDs) has not been demonstrated. During 2012–2016, TickNET collaborators conducted a randomized, blinded, placebo-controlled trial among 622 Connecticut households. Each household received active (containing fipronil wick) or placebo (empty) bait boxes in their yards over two consecutive years. Information on tick encounters and TBDs among household members was collected through biannual surveys. Nymphal ticks were collected from a subset of 100 properties during spring at baseline, during treatment, and in the year post-intervention. Demographic and property characteristics did not differ between treatment groups. There were no significant differences post-intervention between treatment groups with respect to tick density or pathogen infection rates, nor for tick encounters or TBDs among household members. We found no evidence that rodent-targeted bait boxes disrupt pathogen transmission cycles or significantly reduce household risk of tick exposure or TBDs. The effectiveness of this intervention may depend on scale of use or local enzootic cycles.

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DISCLAIMER
The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention or the other participating organizations.

PREVIOUS PRESENTATION
The results of this study were presented, in part, at the 15th International Conference on Lyme Borreliosis and Tick-Borne Diseases (Atlanta, GA) in September, 2018, and the 35th Annual Meeting of the Connecticut Infectious Disease Society in May 2017.

CONFLICT OF INTEREST
The authors declare that they have no competing financial conflicts of interests.

SUPPORTING INFORMATION
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Keywords

bait boxes; humans; pesticide; prevention; rodents; tickborne diseases; ticks

1 | INTRODUCTION

Tickborne diseases (TBDs) are some of the most common notifiable infectious diseases in the northeastern USA, with an average of 2,600 confirmed and probable human cases reported annually in Connecticut alone (Centers for Disease Control & Prevention; Connecticut Department of Public Health, 2021a). In this region of the USA, TBD pathogens are most often transmitted through the bite of *Ixodes scapularis* (blacklegged) ticks. These *Ixodes*-transmitted pathogens primarily include *Borrelia burgdorferi*, the causative agent of Lyme disease, *Anaplasma phagocytophilum* and *Babesia microti* (Steere, 2001).

I. scapularis larvae acquire pathogens while feeding on infected birds and small mammals, including the white footed mouse, *Peromyscus leucopus*, an important reservoir host. Infections are retained as larvae become nymphs, and as nymphs become adult ticks (Mather et al., 1989). Humans acquire TBDs incidentally, most often through the bite of infected nymphs (Eisen & Eisen, 2018; Hayes & Piesman, 2003). In the northeastern USA, exposure to *I. scapularis* ticks is considered highest around the home due to the relative abundance of time spent on one's own property, along with the presence of environmental factors conducive to tick survival (e.g. vegetation and rodent hosts) (Falco & Fish, 1988; Hayes & Piesman, 2003; Maupin et al., 1991; Mead et al., 2018; Steere, 2001).

Reducing ticks on rodent hosts in the peridomestic environment is an approach that could diminish human exposure to ticks and their associated pathogens (Duffy et al., 1994; Piesman, 2006; Stafford & Magnarelli, 1993). Rodent bait boxes targeting white-footed mice have been developed for this purpose and are reported to provide protection against ticks for up to 7 weeks (Dolan et al., 2004). They contain wicks loaded with a topical acaricide (fipronil) that are positioned to brush and treat rodents upon entry to the box. Compared to area-wide acaricide applications, bait boxes can be implemented through an entire season to affect multiple tick life stages (i.e., multiple points in the transmission cycle of tickborne pathogens), are less affected by temperature and precipitation and can provide coverage to an entire yard using a much smaller amount of pesticide (Dolan et al., 2004; Hayes & Piesman, 2003). In addition, bait boxes are one of the few currently available interventions with the purported potential to break the TBD pathogen transmission cycle among reservoir hosts to effectively reduce the infection rate in ticks (Dolan et al., 2004).

While bait boxes have been shown to reduce tick populations on animals and in the field in small entomologic studies, their utility for protecting humans from Lyme disease or other TBDs has not been demonstrated (Dolan et al., 2004; Jordan & Schulze, 2019; Schulze et al., 2017; Williams et al., 2018). We conducted a single-blinded, randomized, placebo-controlled trial to evaluate the effectiveness of rodent-targeted bait boxes in yards to prevent tick encounters and TBDs. This study was conducted as part of TickNET (Mead et

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al., 2015), an ongoing collaboration between the Centers for Disease Control and Prevention (CDC) and the Emerging Infections Program (EIP) in Connecticut.

2 | METHODS

2.1 | Study location and enrolment

This study was conducted in Fairfield and Litchfield counties, CT, areas of consistently high annual incidence of Lyme disease (Connecticut Department of Public Health, 2021b). We initially identified potential participants using a commercial marketing database to select addresses having a freestanding, single family home of three or more people. We used Geographic Information Systems (GIS) technology to further limit those addresses to property sizes of between ½ and 5 acres, representing areas more likely to contain tick habitat. Eligible households were then recruited through targeted mailings to participate in the study for three years each (spring 2012 – winter 2014/2015; or spring 2013 – winter 2015/2016). Information regarding sample size estimation is included in the Appendix S1.

For each household, we asked one adult, who had the authority to allow for licensed pest control operators that were contracted for this study to place bait boxes on their property, to provide written consent to participate as the ‘head of household’ and to respond to surveys on behalf of all household members. During an introductory telephone survey, we asked additional eligibility, demographic and property-related questions. If the respondent reported having an intact deer fence (≥5 feet high) around the entire perimeter of their property, or reported using acaricidal or insecticidal products outside on their property for any reason since the previous summer, their household was deemed ineligible for this study. Participants received up to $120 over three years as compensation for their time. The protocol for this study was reviewed and approved by ethics committees at CDC, Yale University, Western Connecticut State University, and the Connecticut Department of Public Health. This study was not subject to clinical trial registration given bait boxes are not US FDA-regulated devices or drug products (as defined in 42 CFR 11.10).

2.2 | Intervention

We randomly assigned all participating households to an active bait box (treatment) or placebo group, with equal group sizes. Study coordinators and households were blinded to the assigned groups until the end of the study. Due to the physical differences between active and placebo bait boxes, pest control operators could not be blinded, but were asked not to disclose treatment group information to participants or study coordinators.

Households assigned to the active bait box group received commercially available bait boxes (Tick Box Technology Corporation) containing bait and a mounted wick treated with 0.70% fipronil (5-amino-1-(2,6-dichloro-4-(trifluoromethyl) Phenyl)-4-((1,R,S)- (trifluoromethyl) sulfinyl)-1-H-pyrazole-3-carbonitrile); households assigned to the placebo group received bait boxes having no bait and no wick. During installation, all bait boxes were shrouded in protective metal covers and staked to the ground to prevent being damaged or displaced by non-target animals. Once installed, active and placebo boxes were indistinguishable.

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Pest control operators installed bait boxes in a single line on all accessible property sides up to 3 m into the natural vegetation, including woods or brushy areas, from the edge of maintained landscape, according to the manufacturer's label (Tick Box Technology Corporation, 2012). For the treatment group, active bait boxes were placed approximately 10 m apart. For the placebo group, bait boxes were placed 20–25 m apart. Bait boxes were also placed along unsealed rock walls and wood piles located at or near the wooded edge when there was evidence of rodent use or harborage.

Active and placebo bait boxes were installed in the yards of participating households during three separate seasons over two consecutive years to act on multiple life stages of *I. scapularis* ticks. The first round of bait boxes was deployed in summer/fall (late July through late October) of the first year of study to target larval ticks on rodent hosts. A second round replaced the first round and was deployed the following spring/summer (early May through late July) in the second year of study to target nymphal ticks on rodents. A third round was deployed in summer/fall (late July through late October) of the second year of study to again target larval ticks on rodents. During the third year of study, no bait boxes were deployed. Given the seasonal activity and two-year life cycle of *I. scapularis* ticks in the Northeast, it was expected that any impact due to the intervention on larval ticks would be observed on nymphal tick populations in the subsequent spring.

2.3 | Entomologic outcomes

Study investigators collected host-seeking ticks from a randomly selected subset (~10%) of active bait box and placebo treated properties twice from late May to early July at Baseline and in years 1 and 2 of the study to evaluate impact on nymphal *Ixodes* tick populations. Up to forty 30-s samples were conducted using a 1 m by 0.5 m flannel flag to estimate tick density (number of nymphs collected per hour) (Mather et al., 1996). Tick sampling was performed in wooded and brushy vegetation and leaf litter located within 3 m of maintained lawn, and 3 m into lawn areas adjacent to wooded/brushy vegetation and leaf litter (Maupin et al., 1991). Used flags were replaced with clean flags before sampling each property.

All collected ticks were identified to species and stage, preserved in 95% ethanol and stored at −80C. Nymphal *I. scapularis* ticks were sent to CDC's Division of Vector-Borne Diseases in Fort Collins, CO, for PCR detection of *A. phagocytophilum*, *B. microti*, and *B. burgdorferi* using methods previously described (Hojgaard et al., 2014a; Hojgaard et al., 2014b).

2.4 | Human outcomes

Study investigators administered two phone-based surveys each year (six total) to all heads of household; these occurred once each summer (late August) and once each winter (December/January). Survey questions pertained to the number and type of ticks found on household members during the preceding three months, as well as to the occurrence of any TBD diagnoses since last surveyed (or enrolled) among household members. Reports of illness were validated by medical record review, whenever possible. During the last survey, additional questions were asked about perceived treatment assignment to evaluate the

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efficacy of the blinding, and occurrence of other possible pesticide treatments on participant properties during the course of the study.

2.5 | Statistical analyses

Data from the two years of enrolment were combined and analysed at the household level using an intention-to-treat approach (Woodward, 2005). Randomization for group assignments and analyses were performed using SAS 9.3 and R 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria). Proportions or means between treatment groups for household and property characteristics were compared using chi-squared and *t*-tests, as appropriate. Associated confidence intervals (CIs) were adjusted for multiple comparisons by group of related characteristics using a Bonferroni adjustment. Poisson regression was used to measure the effect (rate ratios) of the treatment on tick numbers and tick density across time. The measure of association (odds ratios) between treatment and tick pathogen infection rates over time were modelled using a binomial regression model with a log link.

To account for missing data in certain variables (ranging from 0.2% to 34.6% missing), multiple imputation was used, for which three completed datasets were generated. Each completed data set was used to model the presence or number of ticks on household members (using logistic and Poisson regression, respectively) separately, and estimates from the models were averaged for the final results (Ruben, 1987). Imputation, regression analyses and pathogen comparisons were performed using the ‘mi’, ‘lme4’ and ‘emmeans’ packages for R software.

3 | RESULTS

3.1 | Participation, treatment group assignment, and intervention

Study coordinators mailed over 37,000 flyers to potential participants and received inquiries from over 1,500 individuals. They then contacted households to ascertain eligibility and obtain consent in the order of inquiry, until they reached the target enrolment number of 625 households. Of those contacted, 231 were not eligible or no longer interested; 32 eligible households did not provide written consent and were not included in the study. Ultimately, 622 households were enrolled and treated (at least one time). About half (313, 50.3%) were randomly assigned to receive active bait boxes on their property; 309 (49.7%) were assigned to receive placebo boxes (Figure 1). After randomization, no household characteristics were statistically significantly different between households in the active bait box group versus those in the placebo group (Table 1). In total, 609 households received all three bait box installments (Figure 1), including 307 households with active bait boxes (mean 10.0 boxes per property; range 2–20) and 302 households with placebo bait boxes (mean 5.5 boxes per property; range 2–18). Over the course of the study, 29 households withdrew (16 in the active bait box group, 13 in the placebo group) and 21 households were lost to follow-up (nine in the active bait box group, 12 in the placebo group).

3.2 | Entomologic outcomes

Pre- and post-treatment tick sampling was conducted on 100 properties (51 in the active bait box group, 49 in the placebo group), and a total of 3,237 ticks were collected across all

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properties and all years. At baseline (pre-treatment) in the first year of study, the average nymphal density was 12.5 nymphs per hour (Standard deviation (*SD*) 21.1) on active bait box properties compared to 21.6 nymphs per hour (*SD* 34.0) on placebo properties. In year 1 post-treatment, 12.7 nymphs per hour (*SD* 12.4) were collected on active bait box properties compared to 21.2 nymphs per hour (*SD* 25.8) on placebo properties. In year 2 post-treatment, 13.1 nymphs per hour (*SD* 14.2) were collected on active bait box properties, while 19.8 nymphs per hour (*SD* 30.2) were collected on placebo properties (Figure 2). Overall, there was no statistically significant difference in nymphal density between active bait box and placebo properties over the two full treatment years, with rate ratio (RR) = 1.51 (95% CI: 0.98, 2.34).

A total of 3,184 ticks were able to be tested to estimate nymphal infection rates for each study year and by treatment group (Table 2). Overall, 13.4% (95% CI: 12.3%, 14.6%), 2.0% (95% CI: 1.6%, 2.6%) and 3.3% (95% CI: 2.7%, 4.0%) of nymphs were infected with *B. burgdorferi, A. phagocytophilum*, and *B. microti,* respectively. Unadjusted rate ratios for infection rates by treatment group and year are presented in Table 2. Tick infection rates with *B. burgdorferi* and *A. phagocytophilum* increased significantly in both the active bait box and placebo groups over the course of study; infection rates for *B. microti* were variable. Adjusted results from the binomial regression model comparing infection rates by treatment group over the course of study were consistent with the unadjusted results in Table 2, indicating a statistically significant difference for *B. microti*, with the active bait box group having a lower rate (RR = 1.74, 95% CI: 1.07, 2.83). There was also a statistically significant difference between treatment groups for *B. burgdorferi,* though the nymphal infection rate was lower in the placebo group (RR = 0.71, 95% CI: 0.54, 0.92).

3.3 | Human outcomes

Among those who had bait boxes installed, 269 (87.6%) heads of household in the active bait box group and 269 (89.1%) in the placebo group provided complete data regarding tick encounters for all 6 surveys. Over the 3 years of the study, at least one tick was reportedly found crawling on a household member for 43.0% (95% CI: 39.1%, 47.0%) of households, and at least one tick was reportedly found attached to a household member for 47.0% (95% CI: 43.0%, 50.9%). When evaluating by individual seasonal surveys (Table 3) and across all 6 surveys, there was no statistically significant difference between treatment groups in the number of households reporting members with at least one tick found crawling on (Odds Ratio (OR) = 0.76, 95% CI: 0.56, 1.04) or attached to them (OR = 1.06, 95% CI: 0.83, 1.37). There was also no statistically significant difference between treatment groups in the number of reported ticks found crawling on (RR = 0.77, 95% CI: 0.55, 1.09) or attached (RR = 1.12, 95% CI: 0.87, 1.44) to household members. However, as expected, there were differences observed from Summer to Winter in ticks crawling (RR = 0.29, 95% CI: 0.22, 0.38) and attached (RR = 0.24, 95% CI: 0.18, 0.34). No household or property characteristics were found to be a confounder or effect modifier of the relationship between ticks crawling or attached and treatment grouping.

Over the three years of study, 83 household members from 75 households reported diagnosis with a TBD by a healthcare provider (Table 3). We observed no statistically significant

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difference between treatment groups in number of households with at least one household member reporting a TBD during any season (Table 3).

No statistically significant difference was observed with respect to blinding (perceived versus actual treatment assignment) between treatment groups. The majority of respondents (n = 331, 58.2%, 95% CI: 54.1%, 62.2%) reported being unsure of their treatment group assignment. In total, nine households (five in active bait box group, four in placebo group) that completed the final survey reported use of some other pesticide treatment in their yard over the course of the study. However, none of the reported products were used to reduce tick populations or known to be acaricidal. Additional results regarding entomologic and human outcomes are available in Appendix S1.

4 | DISCUSSION

Despite successful randomization and blinding and over three years of evaluation, residential use of pesticide-treated bait boxes did not demonstrate any impacts on measured entomologic or human outcomes in this study. Tick abundance was variable over time and changed similarly for active bait box and placebo groups, likely due to environmental influences unrelated to use of bait boxes. Tick infection rates were either unaffected (*A. phagocytophilum*) or changed inconsistently across pathogens (*B. burgdorferi* and *B. microti*) in relation to treatment. The number of households reporting tick encounters and TBDs was similar regardless of treatment group throughout the study. The results for these human outcomes are consistent with the apparent lack of impact of active bait boxes on host-seeking nymphal tick populations and tick pathogen prevalence.

We used a randomized placebo-controlled study design to control for potential biases in our evaluation of treatment and outcome. The critical conceptual feature of this design is that with randomization and a large sample size, the two study arms will be comparable for all but the rarest of traits. This comparability extends not just to measured variables (e.g., property size) but also to unmeasured and unmeasurable risk factors and confounders (e.g., tick habitat, outdoor activity, health insurance, proper tick identification skills). Data presented in Tables 1 and 3 confirm that there were no detectable differences between the two treatment groups at enrolment over a wide range of factors. There are some apparent differences in tick abundance across groups, but this is because only a small number of properties were sampled for questing nymphal ticks, and tick density is highly heterogeneous across small spatial scales. Sampling all properties would likely have resolved these stochastic differences. Regardless, there was no observed impact on this entomologic measure over time due to the intervention, results that were supported by our primary outcomes of interest, tick encounters and tickborne disease, from all participating, successfully randomized households.

Our results are at odds with previous evaluations of pesticide-treated bait boxes regarding suppression of host-seeking ticks in residential settings. These studies were all conducted in CT or NJ and differed from our study and each other with respect to a number of factors, including: design of bait box (Protecta Jr., Maxforce, and Select TCS), method/distance of bait box placement (single versus 2 rows; 10–25 m apart), treatment area coverage as

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contiguous versus individual properties, host composition in area of study, and setting for control areas (residential properties versus woodland areas) (Dolan et al., 2004; Jordan & Schulze, 2019; Schulze et al., 2007, 2017; Williams et al., 2018). In previous studies evaluating bait boxes as a single-intervention (Dolan et al., 2004; Jordan & Schulze, 2019; Schulze et al., 2017), host-seeking nymphal *I. scapularis* populations in treated areas were 68%–97% lower as compared to control areas. The greatest suppression of host-seeking ticks was reported in the New Jersey evaluation by Schulze et al. (Schulze et al., 2017), where Select TCS bait boxes were placed on only nine residential properties in 1–2 rows (10 m apart), depending on habitat, and compared to a single untreated plot at a wildlife management area. Studies utilizing two rows of boxes have generally reported higher suppression of host-seeking ticks (Jordan & Schulze, 2019; Schulze et al., 2017), although Dolan et al (Dolan et al., 2004) reported a > 90% reduction in questing *Ixodes* populations after deployment of a single row of Protecta Jr. boxes at one location (13 contiguous properties) on Mason’s Island, as compared with control sites at undeveloped natural areas. Comparisons between residential treatment areas and woodland control areas may be inappropriate if their ecologic structures are dissimilar. It has been hypothesized that bait boxes may be more effective when used comprehensively over a broad cluster of properties, compared to single non-adjacent properties (Dolan et al., 2004; Williams et al., 2018); however, this has yet to be systematically evaluated and may pose challenges for implementation.

Williams et al. (2018) is the only published study to report on the efficacy of bait boxes to suppress host-seeking ticks in CT using the same devices and placement methodology as used in our study (Williams et al., 2018). In addition to using a single row of active bait boxes placed 10 m apart at treatment properties, this study also used residential properties as controls. However, the Williams study is not directly comparable because the investigators used a combination of approaches, bait boxes and a fungal acaricide spray. The overall result of their combined intervention was a significant reduction in tick abundance over 3 years on treated as compared to control properties. Importantly, the fungal spray was not available during the last year of study, and the use of bait boxes alone did not maintain previous levels of control. This suggests that the impact on tick populations in the early years of the study could have been due to use of the fungal spray alone. Multiple interventions add complexity to any study, and it may be necessary to concurrently investigate the efficacy of individual interventions for reducing human exposure while testing them in combination.

Our study has limitations to consider. First, we did not evaluate the frequency or type of rodents using the bait boxes. The efficacy of bait boxes is likely affected by varying levels of host diversity and abundance (Eisen & Dolan, 2016; Ostfeld, 2011). In other studies (Dolan et al., 2004; Jordan & Schulze, 2019; Schulze et al., 2017), including one in CT (Williams et al., 2018), small mammal trapping was conducted to assess tick burdens among treated and untreated populations. White-footed mice were predominantly captured and determined to be the primary *B. burgdorferi* reservoir host for those study areas. Because we did not conduct trapping, we were not able to assess if the abundance and infection prevalence of ticks may have been driven by other animals that would not have used or been affected by this type of intervention. We also could not assess any impacts due to migration of untreated mice, chipmunks, or other hosts onto treated properties (Schulze et al., 2017). Also, while

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we attempted to validate tickborne disease reports (see Appendix S1), we did not validate tick encounter data. A recent publication provides evidence that self-reported tick encounters are a good proxy for both self-reported and verified tickborne disease, particularly in areas where *I. scapularis* is the predominant tick species (Hook et al., 2021).

In conclusion, when used in accordance with manufacturer's recommendations, rodent-targeted bait boxes may not disrupt pathogen transmission cycles or significantly reduce household risk of tick exposure or TBDs. The effectiveness of this intervention may vary due to scale of use (e.g., single property versus neighbourhood-wide) or differences in host characteristics or local enzootic cycles. Complex ecologic conditions involved in maintenance of tickborne pathogens make environmental interventions to prevent TBDs challenging.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

ACKNOWLEDGEMENTS

CDC: John Jones, Isabel Sheets, Mark Lamias, Aimee Geissler, Kiersten Kugeler, Marc Dolan, Anna Perea, and Ben Beard. CT EIP: Julie Ray, Tamara Rissman, AmberJean Hansen, Robert Heimer, Roza Tammer. WCSU: student interns.

Funding information

Financial Support for this project was provided through the Centers for Disease Control and Prevention through the Emerging Infections Program (EIP) Cooperative Agreement (grant numbers: 1-U50CK000195 (2012 – 2016) and 6-NU50 CK000488 (2017 – 2021) [CT]

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Impacts

- Rodent-targeted bait boxes have been shown to reduce tick populations on animals and tick abundance in the field in small-scale entomologic studies in the Northeast. We conducted a randomized placebo-controlled study to evaluate the effectiveness of this approach to prevent Lyme and other tickborne diseases in humans.
- When used according to manufacturer’s recommendations, bait box installation in residential yards did not disrupt pathogen transmission cycles, or significantly reduce tick abundance, household risk of tick exposures, or tickborne diseases.
- The effectiveness of this intervention may vary considerably due to scale of use or differences in host characteristics and local enzootic cycles.

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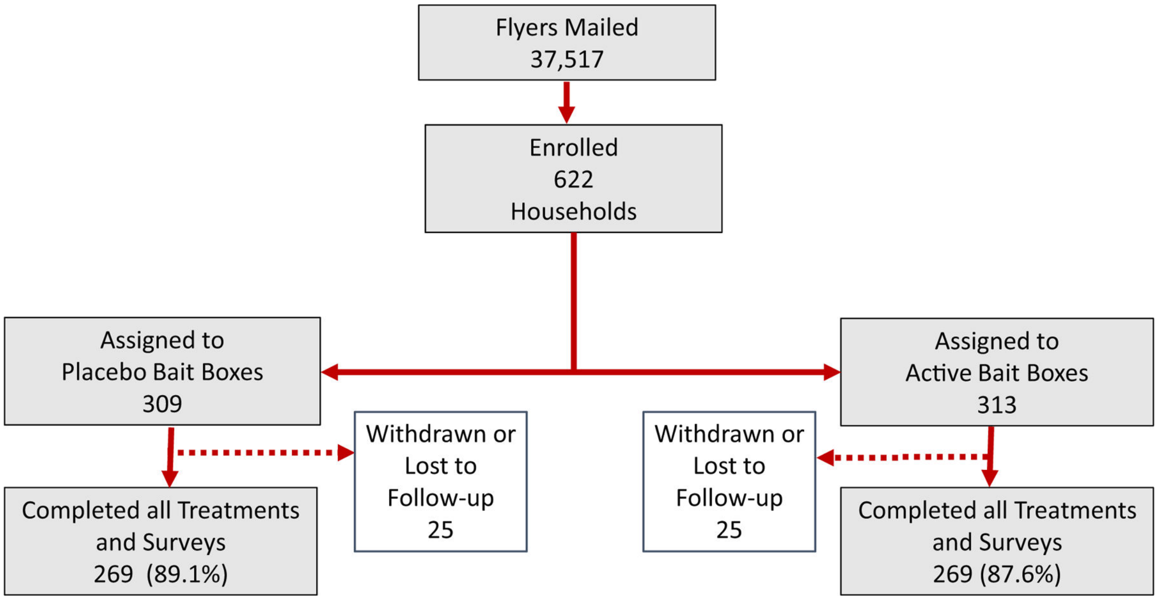

FIGURE 1.

Enrolment, randomized treatment assignments and percent of participating households completing all study activities

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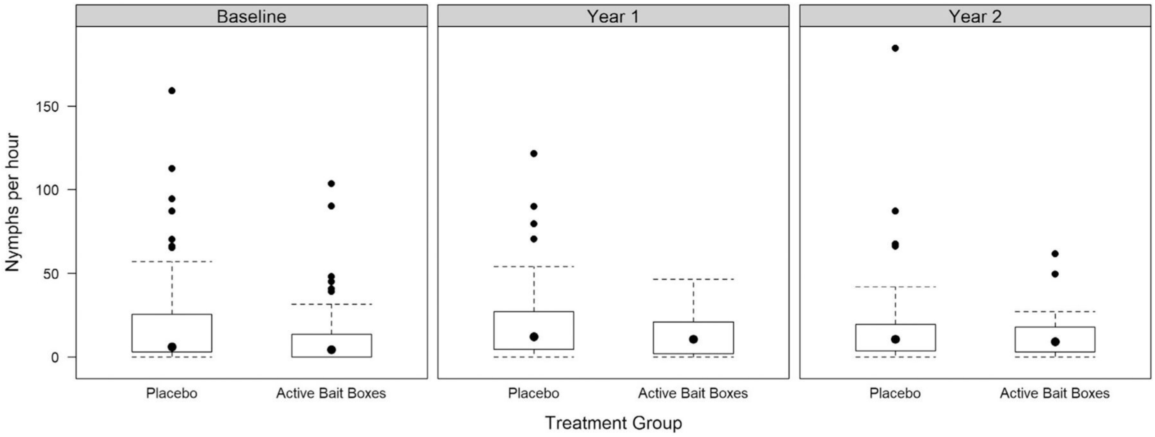

FIGURE 2.

Box and Whiskers plot of *Ixodes scapularis* nymphs recovered per hour by treatment group and year

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TABLE 1

Household demographic and property characteristics by treatment group

Characteristics	Placebo $n = 309$ (%)[a]	Active $n = 313$ (%)[a]	Difference (95% Confidence Intervals)[b]
Household			
Count of household members	1,202	1,192	
Household size (mean)	3.89	3.81	0.08 (−0.1, 0.3)
Age in household (mean)	37.8	38.0	−0.2 (−2.8, 2.4)
Number of households having children	180 (58.6)	180 (58.1)	0.6% (−10.1%, 11.2%)
Number of households having pets	197 (64.0)	170 (54.3)	9.7% (−1.0%, 20.1%)
Race			
White	295 (95.5)	287 (92.3)	3.2% (−2.2%, 8.9%)
Family income			
>$50,000	222 (93.7)	246 (96.5)	−2.8% (−8.9%, 2.7%)
Education			
At least some college	280 (90.9)	291 (93.6)	−2.7% (−8.9%, 3.3%)
Property			
Property size			
≤1 acre	107 (34.7)	88 (28.1)	6.6% (−4.1%, 17.3%)
1 to <2 acres	80 (26.0)	95 (30.4)	−4.4% (−14.7%, 6.0%)
2 to <3 acres	79 (25.7)	72 (23.0)	2.7% (−7.3%, 12.6%)
3+ acres	42 (13.6)	58 (18.5)	−4.9% (−13.5%, 3.7%)
Woods on half or more of property	116 (37.7)	120 (38.6)	−0.9% (−12.1%, 10.3%)
Vegetable garden	120 (39.9)	122 (39.6)	0.2% (−11.1%, 11.6%)
Flower garden	184 (60.3)	203 (65.1)	−4.7% (−15.8%, 6.5%)
Compost pile	106 (34.6)	106 (33.9)	0.8% (−10.2%, 11.7%)
Log pile	244 (79.2)	231 (74.5)	4.7% (−5.1%, 14.5%)
Bird feeder	138 (45.3)	141 (45.5)	−0.2% (−11.7%, 11.3%)
Fencing	127 (41.1)	117 (37.6)	3.5% (−7.8%, 14.7%)
Stone walls	229 (74.8)	227 (73.2)	1.6% (−8.6%, 11.8%)
Recreation area			
Kids equipment	128 (41.6)	117 (37.4)	4.2% (−5.9%, 14.2%)

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Characteristics	**Placebo** ***n* = 309 (%)**[a]	**Active** ***n* = 313 (%)**[a]	**Difference (95% Confidence Intervals)**[b]
Outside dining area	51 (16.6)	50 (16.0)	0.6% (−7.1%, 8.3%)
Outside sitting area	139 (45.1)	139 (44.4)	0.7% (−9.5%, 11.0%)
Lawn sport area	74 (24.0)	78 (24.9)	−0.9% (−9.8%, 8.0%)
Other recreation area	57 (18.6)	63 (20.3)	−1.8% (−10.0%, 6.5%)
Risk perception and exposure			
Believe most likely to get ticks in own yard[c]	172 (74.5)	159 (68.2)	6.2% (−3.2%, 15.6%)
Work outside in tick habitat (at least sometimes)	32 (13.0)	28 (11.2)	1.9% (−4.8%, 8.6%)

[a] Denominators vary due to missing data and removal of ‘don’t know’ answers.

[b] Categorical variables compared using chi-squared test, continuous variables compared using t test. All confidence intervals adjusted for multiple comparisons within a characteristics section using Bonferroni adjustment.

[c] Only asked of participants ($n = 497$) enrolled in 2013.

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TABLE 2

Total number of *I. scapularis* ticks tested and percent infected by pathogen, treatment group and study year

			Percent pathogen infection		
Year	**Treatment group and difference (95% Confidence Intervals)**	**Ticks (*n*)[a]**	***B. burgdorferi***	***A. phagocytophilum***	***B. microti***
Baseline	Placebo	621	11.1	0.8	5.3
	Active	344	12.2	2.3	3.8
	Difference (95% CI)		−1.1 (−5.6, 3.0)	−1.5 (−3.7, 0.0)	1.5 (−1.4, 4.1)
	Total	970	11.4	1.4	4.7
Year 1[b]	Placebo	701	8.8	1.6	1.4
	Active	433	15.9	1.4	
	Difference (95% CI)		−7.1 (−11.3, −3.2)	0.2 (−1.6, 1.6)	1.2 (−0.6, 2.8)
	Total	1,141	11.5	1.5	2.1
Year 2[c]	Placebo	630	17.5	3.0	1.4
	Active	437	17.4	3.4	
	Difference (95% CI)		0.1 (−4.7, 4.6)	−0.4 (2.8, 1.7)	3.0 (1.1, 5.2)
	Total	1,073	17.2	3.2	3.2

[a] Total includes all collected ticks able to be tested and results validated.

[b] Tick collections conducted in late spring/early summer following one late summer/fall placement of bait boxes and during spring placement.

[c] Tick collections conducted in late spring/early summer following all three placements of bait boxes and one spring with no intervention.

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TABLE 3

Number and percent of participating households reporting any tick encounters or physician-diagnosed tickborne disease (TBD) by treatment group and study year

					Number and percent of households reporting[a] any household members with….		
Year	**Timing of survey**	**Survey season**	**Treatment group**	**Households** ***n***	**Ticks crawling** ***n* (%)**	**Ticks attached** ***n* (%)**	**Self-reported TBD** ***n* (%)**
Baseline [b]	Pre-intervention	Summer	Placebo	309	89 (28.8)	68 (22.0)	11 (3.6)
			Active	313	68 (21.7)	61 (19.5)	10 (3.2)
			% Difference (95% CI)		7.1% (−1.3%, 15.4%)	2.5% (−5.3%, 10.4%)	0.3% (−3.4%, 4.3%)
	After 1st round of boxes	Winter	Placebo	303	23 (7.6)	11 (3.6)	5 (1.7)
			Active	306	17 (5.6)	14 (4.6)	3 (1.0)
			% Difference (95% CI)		2.0% (−2.9%, 7.2%)	−0.9% (−5.2%, 3.2%)	0.7% (−2.0%, 3.6%)
Year 1 [c]	After 2nd round of boxes	Summer	Placebo	297	50 (16.8)	55 (18.5)	8 (2.7)
			Active	300	57 (19.0)	67 (22.3)	14 (4.7)
			% Difference (95% CI)		−2.2% (−9.7%, 5.4%)	−3.8% (−11.7%, 4.1%)	−2.0% (−6.2%, 1.9%)
	After 3rd round of boxes	Winter	Placebo	293	17 (5.8)	16 (5.5)	6 (2.1)
			Active	299	6 (2.0)	14 (4.7)	3 (1.0)
			% Difference (95% CI)		3.8% (−0.1%, 8.2%)	0.8% (−3.8%, 5.5%)	1.0% (−1.8%, 4.3%)
Year 2 [d]	Post-intervention	Summer	Placebo	283	43 (15.2)	45 (15.9)	5 (1.8)
			Active	283	34 (12.0)	47 (16.6)	8 (2.8)
			% Difference (95% CI)		3.2% (−3.8%, 10.2%)	−0.7% (−8.2%, 6.8%)	−1.1% (−4.7%, 2.3%)
	Post-intervention	Winter	Placebo	284	29 (10.2)	22 (7.8)	4 (1.4)
			Active	288	19 (6.6)	20 (6.9)	5 (1.7)
			% Difference (95% CI)		3.6% (−2.0%, 9.5%)	0.8% (−4.6%, 6.3%)	−0.3% (−3.5%, 2.8%)

[a] Questions asked about tick encounters in the previous three months and tickborne disease (TBD) diagnosed since the last survey (or since enrolment in spring of Baseline Year).

[b] Two Baseline year surveys were conducted. One survey was conducted in midsummer (July/August), before any active or placebo bait boxes were installed. A second survey was conducted midwinter (December/January), after the first fall bait box placement (install and removal).

[c] Two year 1 surveys were conducted. One survey was conducted in midsummer (July/August), after the spring bait box placement. Another survey was conducted in midwinter (December/January), after the second fall bait box placement.

[d] Two year 2 surveys were conducted. One survey was conducted in midsummer (July/August), following all three bait box placements and one spring with no intervention. Another survey was conducted in midwinter (December/January), after a full year with no intervention.