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SUPPRESSION OF *IXODES SCAPULARIS* (ACARI: IXODIDAE) FOLLOWING ANNUAL HABITAT-TARGETED ACARICIDE APPLICATIONS AGAINST FALL POPULATIONS OF ADULTS

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ABSTRACT. Spring acaricide applications directed against nymphal *Ixodes scapularis* have been shown to be effective, but are perceived by the public as having significant adverse environmental impacts, particularly against nontarget organisms. Targeting the adult stage of *I. scapularis* in the fall would hypothetically result in indirect control of subsequent subadult stages while avoiding other arthropods that are typically inactive during this period. We demonstrate that single fall applications of deltamethrin for 3 consecutive years immediately reduced fall questing adults, while also rapidly reducing the abundance of all postembryonic stages. Deltamethrin applied to the shrub-layer vegetation resulted in levels of control between 97.1% and 100% at 7 days postapplication. Repeated applications against the reproductive stage of *I. scapularis* progressively reduced the abundance of larvae and nymphs in treated plots, reaching 91.4% and 100% by the conclusion of the study.

KEY WORDS *Ixodes scapularis*, deltamethrin, control

INTRODUCTION

The number of cases of *Ixodes scapularis* Say–transmitted diseases continues to escalate in many parts of the United States. In New Jersey, confirmed cases of Lyme disease, human babesiosis, and human granulocytic anaplasmosis have increased ≈1.4-, 3.1-, and 6.2-fold, respectively, in the period 2001–2005 (NJDHSS 2006), while the etiological agents of these diseases have been identified in *I. scapularis* collected from locations across the state (Varde et al. 1998, Schulze et al. 2005). Consequently, the development of reliable interventions to reduce tick-borne disease risk continues to be a public health priority (Stafford and Kitron 2002, Hayes and Piesman 2003).

The critical element in the success of any tick-borne disease intervention program is reducing exposure to infected ticks. Meeting this goal can be achieved through a variety of prevention and education measures. However, Hallman et al. (1995) reported that although 84% of survey respondents were aware of at least one precaution to reduce exposure to ticks, only 43% reported taking any precaution. Given that there are inherent problems with relying solely on education programs, actual reduction in the tick population may be more effective in mitigating risk (Hayes and Piesman 2003). Chemical control is most effectively directed against *I. scapularis* nymphs, the stage epidemiologically linked to the vast majority of Lyme disease cases, and has proven to be the most reliable means of suppressing tick populations (Schulze et al. 1987, 1991; Stafford 1991; Curran et al. 1993; Schulze et al. 2001b). However, the use of habitat-targeted acaricides is generally viewed by the public as having undesirable environmental impacts, including adverse effects on nontarget organisms (Ginsberg 1994).

Barrier acaricide applications directed at *I. scapularis* nymphs have been shown to reduce the potential for human/tick encounters in high-risk areas (Schulze et al. 2007). This strategy, which is suitable for most public health–related tick control programs, minimizes adverse impacts by limiting the amount of acaricide introduced into the environment during the growing season. However, there are occasions when larger-scale tick control efforts are required. For example, in response to a Lyme disease outbreak among U.S. Army reservists conducting field-training exercises in New Jersey, we demonstrated that single applications of carbaryl and diazinon to shrub-layer vegetation in November resulted in significant control of *I. scapularis* adults throughout the fall and spring activity periods (Schulze et al. 1987). Tick populations rebounded by the following fall, apparently because the acaricide applications had no impact on nymphs that were inactive in the litter layer during the application. Theoretically, single fall applications conducted annually against the reproductive stage should result in long-term population reduction. In a recent study, use of the 4-Poster topical treatment device, which targets both fall and spring populations of *I. scapularis* adults parasitizing white-tailed deer (*Odocoileus virginianus* Zimmerman), showed significant reductions in all active stages within 3 years of deployment (Solberg et al. 2003). These results suggest that annual

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habitat-targeted acaricide applications directed at the reproductive stage each fall might similarly suppress *I. scapularis* populations over time, while minimizing nontarget effects by virtue of the timing of the application.

Our working hypothesis was that single acaricide applications against *I. scapularis* adults in the fall for 3 consecutive years would significantly reduce all postembryonic stages of this tick.

MATERIALS AND METHODS

Study site

The study was conducted at the Wayside Training Area within Naval Weapons Station (NWS) Earle, Colts Neck Township, Monmouth County, New Jersey, where *I. scapularis* is consistently abundant (Schulze et al. 1986, Schulze and Jordan 1996). The forest canopy of this ≈60-ha site consists of pitch pine (*Pinus rigida* Miller) and mixed hardwoods, including red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), and chestnut oak (*Q. prinus* L.). The understory is composed of saplings of the dominant canopy species together with sassafras (*Sassafras albidum* (Nuttall) Nees), American holly (*Ilex opaca* Aiton), and black cherry (*Prunus serotina* Ehrh.). Highbush blueberry (*Vaccinium corymbosum* L.), lowbush blueberry (*V. angustifolium* Aiton), huckleberries (*Gaylussacia* spp.), laurels (*Kalmia* spp.), and greenbriar (*Smilax rotundifolia* L.) dominated the shrub layer.

Tick collections

We established 2 treatment and 2 untreated control plots, each 1 ha in area. Abundance of all postembryonic stages of questing *I. scapularis* was monitored at each plot by sampling 10 100-m transects, using a combination of walking and drag sampling methods (Ginsberg and Ewing 1989, Schulze et al. 1997). Tick drags used to survey adults were constructed of 1-m^2 pieces of light-colored corduroy fastened to 1-cm-diam wooden dowels along the leading edge, while heavy-duty steel springs were sewn into the trailing edge of the drag for added weight and flexibility to improve performance when being dragged through dense vegetation. The drags were pulled alongside of each investigator by means of a 2-m rope handle attached to the ends of the wooden dowels. Adult ticks adhering to investigators' clothing and drags were counted and returned to each transect at 20-m intervals. To collect subadult ticks, we used a previously described modified flagging method that has proven effective in dense shrub layers that prevent traditional drag sampling (Schulze et al. 2002). The smaller flags were "mopped" between plant stems within the leaf litter along each transect and examined at 5-m intervals. Ticks found on flags and coveralls were counted and returned to their respective transect. Dragging and walking surveys were conducted simultaneously by the same individuals between 0800 and 1200 h when vegetation was dry and wind speed was consistently below 10 km/h.

Beginning in spring 2004 and in all subsequent years of the study, *I. scapularis* abundance was assessed by sampling all transects on 3 different dates during the peak activity period of each postembryonic stage (Schulze et al. 1986), specifically mid-March through April for spring adults, mid-May through mid-June for nymphs, and August for larvae. Fall adult *I. scapularis* were surveyed between mid- and late October. Following single applications of acaricide in the fall of 2004, all plots were sampled at 1-day and 7-day intervals posttreatment to document the efficacy of the application against *I. scapularis* adults. In 2005 and 2006, we sampled only at 7 days postapplication.

Acaricide applications

Deltamethrin (Suspend SC Insecticide, 4.75% [AI]; Bayer Environmental Science, Montvale, NJ) was applied according to labeling recommendations to the shrub layer of the treatment plots, using a truck-mounted, high-pressure (800-psi) hydraulic sprayer at a rate of 0.09 kg/ha. The applications were performed during the last week of October, 2004–06.

Statistical analysis

Preapplication abundance of host-seeking *I. scapularis* was compared between treatment and control plots using Mann–Whitney *U*-tests (Sokal and Rohlf 1981). Kruskal–Wallis tests were used to compare means of treatment and control plots for each sampling date (Sokal and Rohlf 1981). Post hoc comparisons of mean ranks were performed after Siegel and Castellan (1988). An algebraic variation of Henderson's formula was used to calculate percent control of ticks on acaricide-treated plots: percent control = 100 − ($T/U \times 100$), where T and U are the mean after treatment/mean before treatment in treated plots and untreated plots, respectively (Henderson and Tilton 1955, Mount et al. 1976). All statistical tests were performed using Statistica analysis packages (StatSoft 1995).

RESULTS

Direct effects of acaricide applications against adults

The abundance of fall adults was higher in the treatment compared to control plots during preapplication sampling in 2004 (Mann–Whitney $U_{(20,20)} = 53.50$; $P < 0.01$) (Table 1). The initial fall 2004 application of deltamethrin provided 96.4% control within 1 day and 97.1% control through 7 days, while tick abundance in the untreated control plots was statistically similar or higher than pretreatment means (Table 1). Preapplication numbers of adults in fall 2005 were significantly lower than preapplication abundance in 2004 and were similar to the postapplication abundance observed in 2004. Subsequent applications in fall 2005 and 2006 resulted in 100% control of adults in the treatment plots, while adults in untreated control plots were statistically similar to or higher than the 2004 preapplication means (Table 1).

Indirect effects of acaricide applications against subadults

Preapplication sampling of plots in 2004 showed higher abundance of spring adults and nymphs in treatment plots compared to controls, while larval numbers were statistically equivalent (Table 2). Numbers of spring *I. scapularis* adults in 2005, 2006, and 2007 were reduced in the treated plots relative to both their 2004 numbers and to abundance in the untreated control plots (Table 2). We also found significantly fewer nymphs and larvae in the treated plots in 2005, 2006, and 2007. While nymphal abundance in the control plots did not vary over 3 years, we saw 80% control of nymphs in the 1st spring and 100% control in the 2nd and 3rd. Larval abundance in the control plots was more variable among years but showed consistent decline in abundance in the treated plots.

DISCUSSION

Deltamethrin applied to forest shrub layers to suppress *I. scapularis* adults resulted in levels of control between 97.1% and 100% at 7 days postapplication, with significant control (96.4%) achieved within 24 h. As expected, control of fall adults resulted in reduced numbers of adults in the following spring, with reductions ≥93.7% in all years. Repeated applications against the reproductive stage of *I. scapularis* progressively reduced larval and nymphal tick abundance, reaching 91.4% and 100% control, respectively, after 3 years. Surprisingly, we observed a reduction in *I. scapularis* nymphs and continued suppression of adults in fall 2005. Given the 2-year life cycle of *I. scapularis*, we would not have anticipated an effect on nymphs or fall adults from the initial 2004 application until 2006. Unlike earlier studies using carbaryl and diazinon (Schulze et al. 1987, 1992), these results suggest that deltamethrin may also have affected imma-

Table 1. Fall abundance of host-seeking adult *Ixodes scapularis* at deltamethrin-treated and untreated plots, Wayside Training Area, October–November, 2004–06.

Location	Year[1] 2004 Preapplication	2004 24 h postapplication	2004 7 days postapplication	2005 Preapplication	2005 7 days postapplication	2006 Preapplication	2006 7 days postapplication	Kruskal–Wallis test results[2]
Untreated plots	1.1 ± 0.2a	1.8 ± 0.4a	2.2 ± 0.4ac	1.2 ± 0.3a	2.1 ± 0.4ac	3.4 ± 0.3b	2.5 ± 0.3bc	$H_{(6,140)} = 74.48$; $P < 0.01$
Treated plots	3.4 ± 0.4a	0.2 ± 0.1 (96.4%)[3]	0.2 ± 0.1 (97.1%)	0.5 ± 0.1	0 (100%)	0.8 ± 0.3	0 (100%)	$H_{(6,140)} = 32.71$; $P < 0.01$

[1] Values are mean ticks collected/100-m transect ± SE; $n = 20$ for all comparisons.
[2] Means in the same row followed by the same letter are not significantly different.
[3] Represents percent control (modified Henderson's equation).

Table 2. Spring–summer host-seeking *Ixodes scapularis* abundance at deltamethrin-treated and untreated plots, Wayside Training Area, 2004–07.

Location	Year[1] Pretreatment 2004	Posttreatment 2005	Posttreatment 2006	Posttreatment 2007	Kruskal–Wallis test results[2]
Spring adults					
Untreated plots	1.6 ± 0.4	1.3 ± 0.2	1.2 ± 0.1	1.7 ± 0.2	$H_{(3,240)} = 0.78$; $P = 0.85$
Treated plots	8.6 ± 1.4a	0.2 ± 0.1 (97.2%)[3]	0.4 ± 0.1 (93.7%)	0.1 ± 0.1 (98.9%)	$H_{(3,240)} = 62.28$; $P < 0.01$
Nymphs					
Untreated plots	8.4 ± 1.5a	5.2 ± 1.4ab	7.6 ± 1.4a	1.7 ± 0.4b	$H_{(3,240)} = 17.84$; $P < 0.01$
Treated plots	13.9 ± 1.3a	1.7 ± 0.6 (80.3%)	0 (100%)	0 (100%)	$H_{(3,240)} = 65.03$; $P < 0.01$
Larvae					
Untreated plots	49.8 ± 7.3a	14.4 ± 1.5b	22.4 ± 3.9b	84.3 ± 16.2a	$H_{(3,240)} = 46.61$; $P < 0.01$
Treated plots	42.4 ± 8.0a	4.9 ± 0.9b (60.0%)	2.9 ± 1.2b (84.8%)	6.2 ± 2.9b (91.4%)	$H_{(3,240)} = 100.67$; $P < 0.01$

[1] Values are mean ticks collected/100-m transect ± SE; $n = 20$ for all comparisons.
[2] Means in the same row followed by the same letter are not significantly different.
[3] Represents percent control (modified Henderson's equation).

ture stages of *I. scapularis* that were inactive in the forest leaf litter at the time of the application.

The results of this study demonstrate that a single fall application of deltamethrin directed against *I. scapularis* adults for 3 consecutive years rapidly and dramatically reduced the abundance of all postembryonic stages. These results are comparable to those reported by Solberg et al. (2003), which showed 91–100% reduction of all stages of host-seeking ticks following a 3-year deployment of 4-Posters. Although both control methods target the reproductive stage of *I. scapularis*, each has advantages and disadvantages. Because a single 4-Poster can theoretically treat all deer within a 20-ha area (Solberg et al. 2003, Schulze et al. 2007), this technology can effectively and economically control ticks over large tracts of land. However, conventional acaricide applications may be more economical when controlling ticks in smaller areas. For example, Solberg et al. (2003) reported the operational cost to be ≈$100/4-Poster per week, so that 2 typical 8-wk deployments in fall and spring would cost $1,600/4-Poster or $80/ha. Because the treated area in this study was only 2 ha, the operational cost would effectively be $800/ha. By comparison, the cost of the single fall application of deltamethrin in this study was $325/ha. Although the break-even point of these control methods is ≈5 ha, a single habitat-targeted acaricide application eliminates the need for weekly or semiweekly operational maintenance of the 4-Poster devices. Further, the widespread use of the 4-Poster faces several hurdles, including labeling restrictions that limit its deployment to residential areas with low housing density and regulations in several states that prohibit feeding deer because of concerns about the spread of wildlife diseases. However, where the use of the 4-Poster is restricted or uneconomical, our results show that sequential conventional acaricide applications against the reproductive stage of *I. scapularis*, made to shrub-layer vegetation at a time of year when most nontarget forest arthropods are inactive and unlikely to encounter the acaricide (Schulze et al. 2001a), provides another approach to tick control.

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