Effects of Barrier Application of Granular Deltamethrin on Subadult *Ixodes scapularis* (Acari: Ixodidae) and Nontarget Forest Floor Arthropods

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ABSTRACT We evaluated the effects of a single application of granular deltamethrin made against nymphal *Ixodes scapularis* Say on the diversity and abundance of forest arthropods taken in pitfall traps in oak forest sites for 16 wk after treatment in central New Jersey. Control of *I. scapularis* subadults on treated plots ranged between 97 and 100% and continued at least 12 wk postapplication. Significant short-term changes in arthropod assemblages were detected at one of three study sites within 4 wk posttreatment. Effects were not distributed equally across taxa. Seasonal changes in numbers and diversity of forest arthropods in the study areas may have affected the impact of the acaricide in the treatment area. Comparison with control areas indicated that reductions in abundance of some arthropod taxa in the treatment area were detectable 12 wk after treatment. Total arthropod species diversity was not significantly affected by the application, and no treatment effects were detected 16 wk postapplication, suggesting that the arthropod community had recovered from the effects of the application. The merits of barrier applications in integrated tick control programs are discussed.

KEY WORDS *Ixodes scapularis*, deltamethrin, nontarget effects

LYME DISEASE IS THE MOST common vector-borne disease in the United States, and in 2002 alone, the number of confirmed cases nationwide increased by 39% (CDC 2004). Over the past 3 yr, New Jersey reported an average of >2,400 confirmed cases annually (CDC 2004). The blacklegged tick, *Ixodes scapularis* Say, is the principal vector of Lyme disease spirochetes, and because of its epidemiological importance in the disease transmission cycle (Piesman et al. 1987), its nymphal stage is most frequently targeted for control. Although conventional acaricide applications have been shown to be the most reliable control method against host-seeking *I. scapularis* nymphs (Stafford 1991; Schulze et al. 1991; Solberg et al. 1992; Curran et al. 1993; Schulze et al. 1994, 2001b), chemical control is often perceived to have adverse effects on nontarget organisms (Ginsberg 1994). Although acaricides labeled for tick control are reported to have low residual activity (Howard 1991), previous studies have shown that high-dosage applications can leave persistent residues in some environments (Hoy and Shea 1981, Hastings et al. 1998). However, these potential impacts may be mitigated by a single, well-timed acaricide application that can substantially suppress nymphal *I. scapularis* throughout its entire activity period (Schulze and Jordan 1995). We report here the results of a study to evaluate the effects of a single application along the woodland edges of residential areas ("barrier application") of granular deltamethrin against *I. scapularis* nymphs and its impact on nontarget surface-active (epigaeic) terrestrial arthropods.

Materials and Methods

Study Area. The study area, located in Perrineville, Monmouth County, New Jersey, comprised 48 developed residential properties and three undeveloped building lots, with an average lot size of ≈1.5 ha. Populations of *I. scapularis* have been shown to be consistently abundant at this site (Schulze and Jordan 1995, 2001b). The 10–15-m forest canopy was dominated by chestnut oak, *Quercus prinus* L.; red oak, *Quercus rubra* L.; white oak, *Quercus alba* L.; and American beech, *Fagus grandifolia* Ehrh. Understory species included saplings of the dominant trees together with American holly; *Ilex opaca* Ait., and sassafras, *Sassafras albidum* [Nutt.] Nees. Highbush blueberry, *Vaccinium corymbosum* L.; lowbush blueberry, *V. angustifolium* Ait.; and huckleberries, *Gaylussacia* spp., were the dominant shrub layer species.

Acaricide Applications. Granular deltamethrin [(S)-α-cyano-3-phenoxybenzyl (1*R*,3*R*)-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropanecarboxylate)] (DeltaGard G Insecticide Granule, 0.1% [AI], Aventis Environmental Science USA LP, Montvale, NJ) was applied to 37 of 48 residential properties at a rate of 0.15 kg/ha

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along the woodland/lawn interface to a distance of 8.0 m into the woodland. These barrier applications were made on 27 and 28 May 2002 during the peak activity period of nymphs (Schulze et al. 1986) by using a chest-mounted EV-N-SPRED model 3100 Commercial Crank Seeder (Earthway Products, Inc., Bristol, IN) (Schulze et al. 2001b).

Tick Collections. Pre- and postapplication populations of host-seeking subadult *I. scapularis* were monitored by drag sampling (Ginsberg and Ewing 1989, Schulze et al. 1997) ten 100-m^2 plots located within woodland habitat in the barrier treatment area and ten 100-m^2 control plots placed outside the treatment areas in adjacent forest. To accommodate the barrier application design, the dimensions of all plots were 5 by 20 m. Collections were made between 0800 and 1200 hours on each of the sampling dates by working the drags over the leaf litter of each of the treatment and control plots. Ticks found on drags were removed at 10-m intervals and returned to their respective plots. Nymphs were sampled once before the application and at ≈1, 3, 4, 5, and 6 wk postapplication, whereas larval populations were monitored at ≈ 8 and 12 wk postapplication.

Arthropod Sampling. Nontarget arthropods were sampled from six 100-m^2 plots (5 by 20 m) located within the barrier treatment area and six 100-m^2 control plots. Two plots each were located on three residential properties (Alpine Drive, Elm Court, and Evergreen Court) that received barrier applications of deltamethrin, whereas their respective control plots were established on nearby untreated properties. At each treatment and control plot, six pitfall traps (model 65-4130, Carolina Biological Supply Co., Burlington, NC) were installed within the center of each plot at ≈4 m from the lawn/forest edge and arranged in a 1-m-diameter circle. The minimum spacing between plots on any property was 30 m. After the application, pitfall trap collections were performed at weekly intervals from June to September 2002. For each sampling event, the traps were filled with water and left uncovered and unbaited to collect nontarget invertebrates for ≈24 h. After 24 h, the samples were retrieved, combined in a single container, and immediately preserved in 70% ethanol.

Arthropods were identified to family or assigned to an operational taxonomic unit (sensu Martinat et al. 1988) at the family level when correct identification of all specimens in a sample was difficult or impossible. Oliver and Beattie (1996) showed that such morphospecies can provide a robust estimate of species richness across a variety of habitats. Taxa were selected for analysis because they were the most abundant or best represented groups in pitfall trap samples (representing >5% of the total number of individuals collected) or were most likely to encounter the acaricide (i.e., inhabiting either the litter layer or upper soil horizons). Seven abundance or diversity variables derived from the trapping data were used in the analysis. These included total number of arthropod taxa (TOTDIV) and total number of individual arthropods (TOTAB) taken in pitfall samples; total number of ground spider taxa (SPIDDIV, comprising the Araneidae, Clubionidae, Gnaphosidae, and Lycosidae) and total number of spiders (SPIDAB); predator abundance (PREDAB), comprising ground spiders, rove beetles (Staphylinidae), ground beetles (Carabidae), ants (Formicidae), centipedes (Chilopoda), and pseudoscorpions (Pseudoscorpiones); and total number of Isopoda (ISOAB), Coleoptera (COLLAB), Collembola (COLLEM), harvestmen (Opiliones), and Formicidae (FORMAB) (Table 1).

Table 1. Dependent variables for arthropod taxa captured in pitfall traps used in comparisons between treated and untreated plots

Variable	Description
TOTDIV	Total no. of arthropod taxa taken in pitfall samples
TOTAB	Total no. of individual arthropod specimens taken in pitfall samples
SPIDDIV	Total no. of ground spider taxa (including primarily Araneidae, Clubionidae, Gnaphosidae, and Lycosidae) taken in pitfall samples
SPIDAB	Total no. of individual ground spiders taken in pitfall samples
PREDAB	Total predaceous arthropods (including ground spiders, rove beetles [Staphylinidae], ground beetles [Carabidae], ants, centipedes and pseudoscorpions) taken in pitfall samples
ISOAB	Total no. of Isopoda taken in pitfall samples
FORMAB	Total no. of Formicidae taken in pitfall samples
COLLEM	Total no. of Collembola taken in pitfall samples
COLLAB	Total no. of Coleoptera taken in pitfall samples

Leaf Litter Measurements. We have previously shown that leaf litter depth may affect pesticide efficacy (Schulze and Jordan 1995). Depth of leaf litter was measured using a 1-m length of narrow-gauge wire that was driven into the litter layer until the soil surface was encountered. Litter depth was then read from a metric scale. Depth of leaf litter was recorded at five random locations (selected by random number generator from a 2 by 2-m grid superimposed on the sampling plot) at each of the 100-m^2 treatment and control plots. Soil cores were taken at each location using a 7-cm soil auger to measure the depth and texture of the duff layer (Schulze et al. 2002).

Statistical Analysis. Differences in host-seeking *I. scapularis* populations between treatment and control plots were made using Mann–Whitney U tests (Sokal and Rohlf 1981). A modification of Henderson's method was used to calculate percentage control of ticks on acaricide-treated plots: % control = $100-(T/U \times 100)$, where T and U are the mean after treatment and mean before treatment in treated plots and untreated plots, respectively (Henderson and Tilton 1955, Mount et al. 1976). Comparisons between treated and untreated plots were made for total diversity and total abundance of arthropods and for specific taxa taken in pitfall traps. Data from each plot were pooled by sampling date. Mann–Whitney or Kruskal–Wallis one-way tests were used to test for differences between means of treatment and control plots for each sampling date and for edaphic variables (Sokal and Rohlf 1981). We did not attempt between-date comparisons due to high between-date variation

Table 2. Number of questing *I. scapularis* subadults (mean ± SE) collected at treatment and control plots before (20 May 2002) and after deltamethrin application (27–28 May 2002) in Millstone Township, Monmouth County, New Jersey

Date (wk posttreatment)	Plots (n)	Plot location		Mann-Whitney U test
		Treatment	Control	
Nymphs				
Pretreatment	10	7.5 ± 1.3	6.2 ± 0.6	$U_{(10,10)} = 46.0$; $P = 0.76$
1	10	0.1 ± 0.1	7.9 ± 1.6 (98.9)[a]	$U_{(10,10)} = 0.50$; $P < 0.01$
2	10	0.1 ± 0.1	8.1 ± 1.4 (98.9)	$U_{(10,10)} = 52.5$; $P < 0.01$
3	10	0.2 ± 0.1	6.4 ± 1.2 (97.4)	$U_{(10,10)} = 34.0$; $P < 0.01$
4	10	0	3.9 ± 0.9 (100)	$U_{(10,10)} = 10.0$; $P < 0.01$
5	10	0	3.9 ± 0.9 (100)	$U_{(10,10)} = 10.0$; $P < 0.01$
Larvae				
8 wk	10	6.9 ± 2.5	180.4 ± 39.9	$U_{(10,10)} = 1.0$; $P < 0.01$
12 wk	10	5.6 ± 3.4	29.5 ± 6.7	$U_{(10,10)} = 11.0$; $P < 0.01$

[a] Percentage of control (modified Henderson's equation).

in both arthropod diversity and abundance. The null hypothesis was that diversity and abundance of arthropod taxa did not differ between treated and untreated plots. All statistical tests were performed using Statistica analysis packages (StatSoft, Inc. 1995) with $\alpha = 0.05$ for significance of statistical tests. Arthropod voucher specimens from the study remain in our possession.

Results and Discussion

Effects on Ticks. Numbers of *I. scapularis* nymphs before the application did not differ significantly between treatment and control plots (Table 2). Within 1 wk postapplication, the population of nymphs was significantly lower in the treated plots and showed a 98.7% level of control compared with untreated control plots. Significant levels of control continued throughout the remainder of the peak nymphal activity period, ranging between 97.4 and 100%. Populations of larvae, inactive at the time of the application, also were suppressed within the treatment plots throughout much of their activity period (Table 2). Although this level of control of nymphs was not unexpected (Schulze et al. 2001b), the duration of control was impressive and demonstrated that a single, well-time application of deltamethrin significantly reduced both nymphal and larval *I. scapularis* in treated areas. This preliminary study demonstrates that deltamethin is effective in suppressing *I. scapularis* nymphs to levels similar to or greater than those achieved by other commonly used acaricides (Stafford 1991; Schulze et al. 1991, 1994, 2000; Solberg et al. 1992; Curran et al. 1993; Schulze and Jordan 1995), and the low rate of application makes deltamethrin an attractive alternative to the organophospate and carbamate acaricides (Schulze et al. 1991).

Arthropod Collections. Total arthropod diversity (TOTDIV; total number of identified taxa) collected in pitfall traps, regardless of treatment, was 89 (taxa included orders and families) at Elm Court, 66 at Evergreen Court, and 41 at Alpine Drive. In total, 607 individual specimens were collected and identified at Elm Court, 900 at Evergreen Court, and 613 at Alpine Drive. COLLEM far exceeded any other taxon in absolute numbers of individuals captured. At the Elm Court site, COLLEM (27.9% of total captures) were the most abundant arthropods in pitfall samples, followed by beetles (COLLAB) (17.3%), isopods (14.0%), and harvestmen (12.9%). All other taxa represented <5% of total captures. PREDAB comprised 28.1% of total captures. At Evergreen Court, COLLEM (32.6%), beetles (11.3%), and Chilopoda (8.2%) comprised the majority of captures, whereas PREDAB comprised 28.8% of all captures. At Alpine Drive, COLLEM (37.0%) and ISOAB (10.9%) dominated pitfall samples and PREDAB represented 23.6% of captures (Table 3). The terrestrial arthropod diversity and abundance data presented here are similar to those reported previously in similar New Jersey xeric pine and pine–oak forests (Boyd 1995, Schulze et al. 2001a).

Leaf Litter Measurements. Mean leaf litter depth varied significantly among the three treatment areas [Kruskal-Wallis $H_{(2,180)} = 128.01$; $P < 0.01$]. Litter layers were deeper at Evergreen Court (99.2 ± 5.3 mm [mean ± SE], range 84–138 mm) than at either Alpine Drive (77.7 ± 3.4 mm, range = 74–92 mm), or Elm Court (34.2 ± 8.1 mm, range 0–69 mm). The duff layer at Alpine Drive (20.8 1.6 mm, range 0–31 mm) was significantly shallower than at either Elm Court (40.8 ± 4.6, range 23–63 mm) or Evergreen Court (52.5 ± 3.3, range 38–83 mm) [$H_{(2,180)} = 43.58$; $P <$

Table 3. Relative abundance (percentage of total captures across all dates) of major arthropod taxa identified at three study sites in Millstone Township, Monmouth County, New Jersey

Taxon	Study site		
	Elm	Alpine	Evergreen
SPIDAB	4.6	6.8	8.9
COLLAB	17.3	11.3	7.3
COLLEM	27.9	32.6	37.0
FORMAB	3.5	6.4	5.8
ISOAB	14.0	7.3	10.9
Opiliones	12.9	7.7	4.8
Chilopoda	4.5	8.2	2.9
PREDAB	28.1	28.8	23.6

PREDAB includes spiders and relative abundance for predators was calculated separately from SPIDAB so that columns do not sum to 100%.

Table 4. Summary of total arthropod abundance (TOTAB) (mean ± SE per trap) taken in pitfall traps from control and deltamethrin-treated plots after acaricide application at three sites in Millstone Township, Monmouth County, New Jersey, July–Sept. 2002

Location	TOTAB		Mann–Whitney *U* test
	Control plots	Treatment plots	
Elm Court	162.3 ± 18.8	85.3 ± 56.3	$U_{(16,16)} = 24.0$; $P = 0.04$
Alpine Drive	52.7 ± 1.8	50.0 ± 10.0	$U_{(16,16)} = 120.0$; $P = 0.76$
Evergreen Court	69.0 ± 15.4	47.3 ± 7.8	$U_{(16,16)} = 88.0$; $P = 0.13$

0.01]. In contrast to the other two sites, where the litter cover was more or less uniform and consisted of leaves and decaying leaf humus, the litter cover at Elm Court tended to be more patchy and less substantial.

Effects on Nontarget Arthropods. There were no observed effects of the acaricide treatment on TOTAB at either the Alpine Drive or Evergreen Court sites (Table 4). At the Elm Court site, however, numbers of dominant taxa were significantly depressed in the treated plots within 4 wk after the acaricide application (Table 5). COLLEM was significantly reduced within 4 wk of the application, but they had recovered in treatment plots within 8 wk. TOTAB, PREDAB, and COLLAB were depressed in treated plots relative to control plots 8 wk after the application. All had recovered within 12 wk. Numbers of spiders (SPIDAB) and isopods (ISOAB) were depressed within 4 wk of application and continued to be depressed 12 wk postapplication. TOTDIV was not significantly affected by the application, and no treatment effects were detected 16 wk postapplication, suggesting that the arthropod community had recovered from the effects of the application, perhaps through recolonization from surrounding untreated areas.

Although more arthropods were collected at the untreated plots, the compositions of the arthropod assemblages at the treated and untreated plots were similar. Although no comparisons between dates were made, there was observable variation in arthropod numbers in the control plots that may have reflected changes in species phenology. Differences in TOTAB and TOTDIV in the control samples seemed to reflect seasonal variation in insect populations in forest habitats (Berryman et al. 1987, Boyd 1995, Butler et al. 1997). TOTAB varied significantly between months in the control plots [Kruskal-Wallis test: $H_{(4,20)} = 7.47$; $P = 0.02$], indicating seasonal changes in arthropod populations.

This variability in the observed effects of pesticides on different arthropod taxa has been demonstrated previously (Suttman and Barrett 1979, Hoy and Shea 1981). Field studies have shown that pyrethroids affect flying and vegetation-inhabiting arthropods (e.g., predatory beetles) much more than soil-dwelling arthropods (Shires 1985, NRCC 1986). In addition, their evidence suggests that predaceous species may be susceptible to lower doses of pyrethroids than their prey, disrupting the predator–prey relationship (Smith and Stratton 1986, Mueller-Beilschmidt 1990).

Differences in the observed effects of the acaricide application at different sites may have been due to the spatial and temporal distributions of different arthropods, which range widely and are characterized by small patch distributions, complex seasonal and successional sequences, varying dispersal patterns, and rapid population turnovers (Kremen et al. 1993). Also, terrestrial arthropods, because of their sensitivity to microenvironmental gradients, are highly responsive to habitat edge effects (Kremen et al. 1993). Immigration of arthropods across habitat edges and into treated areas is influenced by mobility of taxa and the size of the treatment blocks (Schowalter 1985). Both the Alpine Drive and Evergreen Court sites were edge sites where both the diversity and abundance of mobile arthropods is highest and new colonization most frequent, particularly where the area has been defaunated. The Elm Court site was more typical of a small, forested patch and was isolated from the surrounding woodland by oldfield and lawn.

Previous studies have suggested that small treatment blocks may fail to demonstrate effects of pesticide treatment on some taxa due to the dynamics of colonization and short generation times (Miller 1990, Butler et al. 1997) and that the probability of detecting treatment effects varies directly with arthropod density (Martinat et al. 1988, Butler et al. 1997). This may help to explain our failure to detect an effect of deltamethrin at Evergreen Court and Alpine Drive. However, results at Elm Court indicated significant adverse

Table 5. Comparison of forest litter arthropod abundance and richness (number of individual taxa) in control (C) and deltamethrin-treated (T) plots at the Elm Court study site in Millstone Township, Monmouth County, New Jersey

Taxon	Preapplication		Wk postapplication							
			4		8		12		16	
	C	T	C	T	C	T	C	T	C	T
SPIDAB	2.7 ± 0.8	3.2 ± 0.7	4.5 ± 1.3	3.5 ± 1.4*	3.9 ± 0.7	2.5 ± 0.9*	4.0 ± 2.4	2.5 ± 1.2*	1.0 ± 0.9	2.0 ± 1.5
COLLAB	19.8 ± 3.9	19.0 ± 0.6	12.5 ± 4.1	8.2 ± 1.2*	12.0 ± 2.8	5.0 ± 2.3*	7.3 ± 1.8	5.9 ± 2.2	6.8 ± 1.2	6.3 ± 2.3
ISOAB	12.6 ± 3.9	12.8 ± 8.2	19.7 ± 7.1	3.3 ± 1.1**	14.4 ± 4.3	4.3 ± 1.1**	11.4 ± 4.0	4.3 ± 1.3**	5.0 ± 2.7	4.8 ± 1.3
Opiliones	15.2 ± 5.5	11.8 ± 5.3	7.5 ± 2.8	6.0 ± 1.4	8.8 ± 3.8	7.8 ± 4.1	8.5 ± 3.9	8.0 ± 6.6	1.7 ± 1.7	1.7 ± 0.9
COLLEM	30.0 ± 7.2	25.4 ± 6.1	19.3 ± 7.2	5.0 ± 1.6**	15.8 ± 5.9	12.0 ± 1.1	22.5 ± 10.2	18.0 ± 1.6	8.7 ± 2.3	3.7 ± 1.9
PREDAB	29.4 ± 10.5	29.5 ± 14.7	20.8 ± 3.1	5.6 ± 1.3**	19.0 ± 5.6	7.0 ± 3.6**	12.0 ± 3.3	14.8 ± 1.1	7.0 ± 5.4	5.7 ± 4.4
TOTAB	88.2 ± 16.3	86.6 ± 7.8	74.7 ± 9.8	41.0 ± 6.3*	57.8 ± 7.6	43.0 ± 7.6*	57.3 ± 6.3	49.7 ± 4.8	54.5 ± 10.4	52.8 ± 9.7
TOTDIV	16.0 ± 0.9	15.5 ± 0.8	15.0 ± 0.8	11.8 ± 1.4	15.0 ± 1.0	11.8 ± 0.8	14.0 ± 3.1	12.3 ± 0.7	12.8 ± 1.5	12.5 ± 1.7

Significant Mann–Whitney *U* tests are indicated by $*P < 0.05$ or $**P < 0.01$.

impacts on nontarget arthropods, with some effects continuing at least 12 wk after acaricide applications.

The data presented here suggest that an application of granular deltamethrin may have significant negative effects on nontarget forest arthropods and argue for targeting applications to suppress tick populations only in areas with significant human activity. These types of barrier applications have been shown to be effective in residential areas (Stafford 1991; Curran et al. 1993; Schulze et al. 1994, 2001b). Because newer host-targeted approaches to tick control demonstrate substantial lag times before they become effective (Stafford and Kitron 2002), such barrier applications remain a necessary component of any integrated tick management program by minimizing risk associated with incidental human contact with tick habitat along wooded edges in residential environments.

The available information on pyrethroids indicates that they may pose a serious hazard to nontarget organisms, and the lack of data on the impact of pyrethroids in the environment and on wildlife is a critical gap in our knowledge of these compounds. Previous studies have demonstrated long-term persistence of pesticides after high-dosage applications to forest communities and continued applications of pesticides may result in undesirable accumulations within the sprayed areas (Hoy and Shea 1981, Hastings et al. 1998). Pyrethroids are among the most persistent pesticides in commercial use, especially in soil containing a high proportion of organic matter and can accumulate to levels in excess of the initial concentration if they are repeatedly applied in a single season at rates higher than the rate at which they are degraded (NRCC 1986). In this study, a single, well-timed barrier application controlled >97% of *I. scapularis* nymphs throughout their entire activity period, suggesting that indiscriminate, large-scale and/or repeated acaricide applications, which may be problematic from an environmental standpoint, are unnecessary.

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