NEW JERSEY DEPARTMENT OF HEALTH
A BETTER STATE OF HEALTH

Lyme Disease:

Assessment and Management of Vector Tick Populations in New Jersey

Terry L. Schulze, Ph.D.[1], Louis M. Vasvary, Ph.D.[2] and Robert A. Jordan, Ph.D.[3]

[1] Infectious Disease Program, Division of Epidemiology, Occupational and Environmental Health, New Jersey Department of Health, CN 369, Trenton, New Jersey 08625

[2] Rutgers Cooperative Extension, Cook College, Rutgers, the State University, P.O. Box 231, New Brunswick, New Jersey 08903

[3] Freehold Area Health Department, Municipal Plaza, Schanck Road, Freehold, New Jersey 07728

FOREWARD

The importance of Lyme disease as the most frequently reported arthropod-borne illness in the United States is uniformly acknowledged by the medical community, governmental health agencies, and the public alike. While information on the clinical spectrum, treatment, and epidemiology of Lyme disease is available from a number of sources, few recommendations have been compiled regarding the control of vector tick populations. In recognition of this, the following Extension Bulletin is intended to provide a comprehensive summary of published research conducted in New Jersey and elsewhere on the management of populations of the black-legged tick, *Ixodes scapularis*, in an effort to reduce Lyme disease transmission. Rather than limiting its scope solely to tick control, the Extension Bulletin reviews current information on the biology, ecology, and behavior of this important public health pest. A complete understanding of these factors is critical to the design of site-specific integrated tick management strategies.

Introduction

The decision to initiate control efforts against a pest species is normally based on some perceived unacceptable impact to human well-being, usually caused by an excessive number of the subject pest. Under most situations, the impact of low to moderate populations of the pest is considered below an economic threshold where efforts to reduce the number of pests is either too difficult, too costly, or the collateral impacts to the environment cannot be justified. A possible exception to this premise is when public health is threatened. In the case of Lyme disease, alternatives to the actual reduction of populations of the black-legged tick, *Ixodes scapularis* (formerly the northern deer tick, *Ixodes dammini* [1]), the principal vector of the Lyme disease spirochete (*Borrelia burgdorferi*) in the northeastern United States, have been well publicized. Where Lyme disease is endemic, avoidance of tick-infested areas is the principal means of preventing transmission (2). If avoidance of ticks proves impractical, additional modifications to behavior include wearing light-colored clothing, tucking pant legs into socks, using personal or clothing repellents, and promptly removing attached ticks. The implementation of a control program against *I. scapularis* should be viewed as the final alternative.

Methods for reduction of *I. scapularis* populations as a means of controlling Lyme disease fall within four categories: host reduction, habitat modification, biological control, and chemical control. Each of these methods has distinct technical advantages and disadvantages which must be considered in the design of any control strategy. Environmental considerations, logistics, and public perception all have a profound influence on the selection process. Irrespective of the method eventually chosen, its success is predicated upon a complete understanding of the biology, behavior, and ecology of the target organism (3).

BACKGROUND

Life Cycle of *Ixodes scapularis*

The black-legged tick, *I. scapularis*, passes through four stages of development: egg, larva, nymph, and adult. *Ixodes scapularis* is a three-host tick, meaning that each postembryonic life stage must locate and obtain a bloodmeal from a separate host in order to complete its life cycle. In late winter or early spring after engorgement, the female black-legged tick deposits a single eggmass containing several thousand eggs. The majority of the eggs hatch from July to September into tiny six-legged larvae. Larvae remain at ground level in leaf litter or similar debris and wait for a suitable host to pass by. This host-seeking or "questing" behavior favors the location of smaller animals. After feeding for a period of two to three days, larvae drop off the host, overwinter, and molt to nymphs the following spring. Like larvae, *I. scapularis* nymphs, which now possess eight legs, quest at ground level, again favoring attachment to small animals. Nymphs which fed on infected hosts as larvae will carry the spirochetes through the molt (trans-stadial passage) and may be able to transmit the infection to its next host. Those nymphs that are successful in finding hosts will feed for a period of three to four days, drop off the host, and molt to sexually differentiated adults in the fall. Adult ticks quest on low-lying vegetation, typically the shrub layer of a forest. This host-seeking behavior favors location and attachment to larger mammals. Female *I. scapularis* finding hosts in the fall will generally feed for approximately one week, mate, and overwinter on the host. During the following spring, the female will drop off the host, deposit her eggmass, and die, completing the two-year life cycle.

Activity Periods of *Ixodes scapularis*

The peak activity period of adult ticks in New Jersey is between mid-October and early December (4). Those adults failing to acquire hosts in the fall will enter diapause and become active again the ensuing spring from mid-March through April. Unlike other medically important tick species in the Northeast, *I. scapularis* adults will become active in winter during periods of warming. Although nymphs may be observed from late April through early July, the peak activity period is between late May and early June. Larvae are most abundant in late July and August, but may be found from late June through September. The activity period of each stage is depicted in Figure 1.

Hosts and Reservoirs

Ixodes scapularis is not host-specific, that is, it will feed on a wide variety of hosts. In New Jersey, subadult black- legged ticks were most abundant on the white-footed mouse (*Peromyscus leucopus*), eastern chipmunk (*Tamias striatus*), and eastern gray squirrel (*Sciurus carolinensis*)(5). Other hosts yielding at least one subadult stage of the black-legged tick included the meadow vole (*Microtus pennsylvanicus*), meadow jumping mouse (*Zapus hudsonius*), masked shrew (*Sorex cinerius*), opossum (*Didelphis virginiana*), raccoon (*Procyon lotor*)(5), and 24 species of birds (6). Adult ticks were found on white-tailed deer (*Odocoileus virginianus*)(7), raccoons, opossums, and feral domestic cats (*Felis domesticus*)(5), domestic canines (8), and horses (9). Anderson (10) reviewed

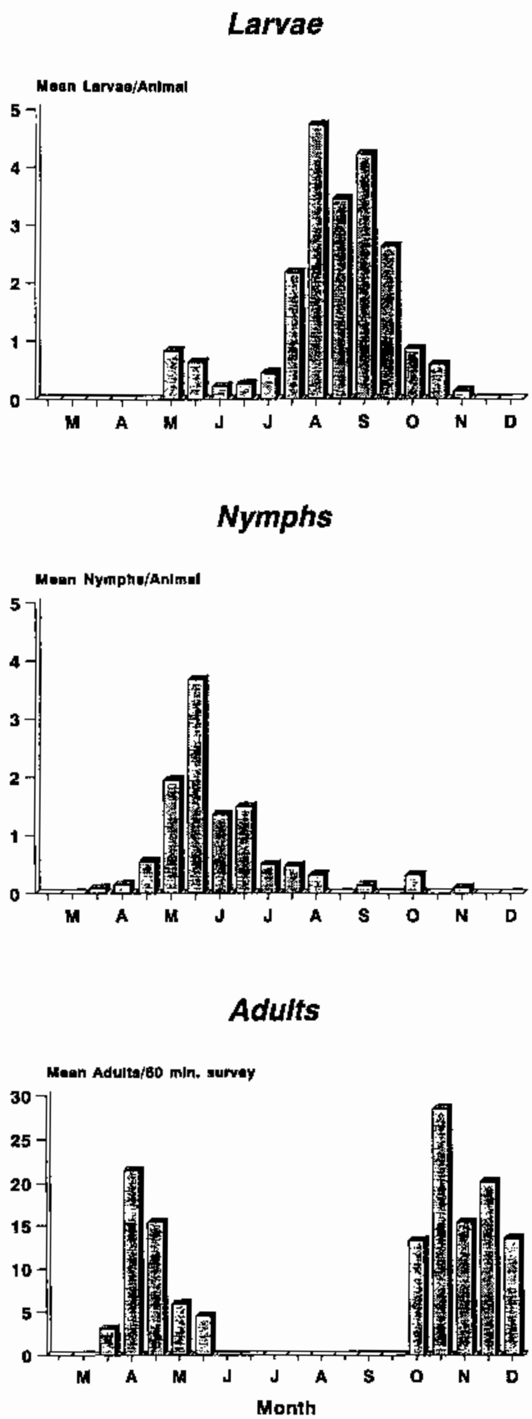

Figure 1. Seasonal activity patterns of *Ixodes scapularis*.

the literature on host associations and reported at least one stage of *I. scapularis* parasitizing 31 mammal species and 49 bird species. In addition to serving as both maintenance and reservoir hosts, birds are also important in the local and regional distribution of subadult *I. scapularis* (6,11). Generally, subadults were found on small mammals and birds, while *I. scapularis* adults were observed on medium- and large-sized mammals. However, all active stages are opportunistic and, for the most part, will parasitize any available host.

While a variety of mammals and birds serve as maintenance hosts, their role as reservoirs for *B. burgdorferi* has not been adequately studied. On Long Island, New York, both white-tailed deer and white-footed mice were found to be spirochetemic (12). Telford et al. (13) subsequently described deer as incompetent reservoirs. Lyme disease spirochetes have also been isolated from raccoons (14), meadow voles (15), woodland jumping mice (*Napaeozapus insignis*) and six bird species (16). At this juncture, it is generally recognized that the white-footed mouse is the principal reservoir host for *B. burgdorferi* (15,17-19). Because spirochetes are maintained trans-stadially with high frequency, *I. scapularis* must also be considered an important reservoir.

Transmission

In nature, *I. scapularis* demonstrates an inordinately high rate of infection with *B. burgdorferi* when compared to most arthropod-borne diseases. In a hyperendemic area of Monmouth County, New Jersey, an average of 46% of *I. scapularis* were found to be infected with *B. burgdorferi* (20), and occasionally reached an infection rate as high as 79% (4). Nymphs on nearby Long Island, New York, yielded infection rates ranging between 12.8% and 28.8% (E.M. Bosler 1993, personal communication). Research in New York and Connecticut showed 1.9% of unengorged larval *I. scapularis* were infected, suggesting that transovarial passage of *B. burgdorferi* is uncommon (21).

The high rate of infection in natural populations of *I. scapularis* is largely due to the temporal relationship of activity periods of each stage. Although representing different generations, the activity of nymphs precedes that of larvae in any given year. As a result, infected nymphs are able to transmit spirochetes to a wide variety of hosts prior to the appearance of larvae, giving the larvae an increased opportunity to acquire *B. burgdorferi* from newly infected hosts. This relationship is augmented by the transstadial passage of *B. burgdorferi*.

Unlike other hematophagous arthropods such as mosquitoes and biting flies, ticks require an extended period of time to insert their mouthparts and initiate the feeding process. Piesman and coworkers (2) showed that *I. scapularis* nymphs transmitted *B. burgdorferi* to 1 of 14 rodents (7.1%) after 24 hours, 5 of 14 rodents (35.7%) after 48 hours, and 13 of 14 rodents (92.9%) after 72 hours, suggesting that in most cases, infected ticks must be attached and feeding for a period of 24 hours or more before transmission occurs. The importance of prompt removal of ticks to reduce the risk of acquiring Lyme disease cannot be overstated.

Ecology of Lyme Disease

Throughout the northeastern United States, *I. scapularis* exploits primarily woodland habitats and associated ecotones in Connecticut (22,23), New York (24,25), Massachusetts (26), and New Jersey (3,5). In endemic areas of New Jersey, *I. scapularis* is most often found in mixed hardwood forests with extensive shrub layers (Photograph 1)(3,27). Brush/shrub associations also serve as adequate habitat (28,29), as do some fields in secondary woody succession (Photograph 2)(3,27), and certain ornamental landscaping associations (Photograph 3)(30). Unfavorable habitats include open sunny areas such as turfgrass (lawns, athletic fields, and other recreational areas), croplands, and wetlands. Lawns immediately adjacent to woodland edge may support low numbers of ticks (Photograph 3)(31).

Although woodlands clearly provide the principal habitat for *I. scapularis*, studies in New York suggested that the majority of Lyme disease cases are the result of exposure to infected black-legged ticks at or near the patient's place of residence (25,32,33). Suburban residential foci of Lyme disease within the Northeast are frequently associated with adjacent or nearby woodlands (24,25,34). Within these residential settings, 88.9% of *I. scapularis* were collected from woods and associated ecotones, 9.1% from ornamental plantings, and 2.0% from maintained lawns (30). The presence of a dense shrub layer, leaf litter, and other plant debris seems to play an important role in the survival of both larvae and nymphs by maintaining conditions of high humidity and by providing cover for hosts. Shrub layer vegetation also furnishes questing sites for adult ticks. In concert with information on the peak activity periods, these data provide the basis for virtually all tick management strategies.

TICK MANAGEMENT

Avoidance and Personal Protection

As stated earlier, avoidance of tick-infested areas is the principal means of preventing exposure to ticks and potential transmission (2). If avoidance of tick-infested areas proves impractical, additional modifications to behavior should be considered. These include the wearing of light-colored clothing, tucking pant legs into socks, judicious use of personal or clothing repellents, frequent self-inspections for ticks, and prompt removal of attached ticks. By following these recommendations, the likelihood of being bitten by infected ticks and acquiring Lyme disease is remote. Therefore, the implementation of a control program against *I. scapularis* may be unnecessary and should only be considered as a final alternative and only after the presence of *I. scapularis* populations has been documented.

Host Reduction

The first published investigation to address control of *I. scapularis* evaluated the effect of deer reduction on tick abundance (35). Attempts to reduce the number of white-tailed deer (*O. virginianus*), the principal host of *I. scapularis* adults, through the use of several trapping techniques and rifle-fired tranquilizers proved impractical. Subsequently, the destruction of approximately 70% of the deer did not markedly reduce tick abundance during the first year. While it can be argued that this study was terminated before the effects of deer reduction were fully manifest, the authors suggested that the failure to reduce the abundance of subadult *I. scapularis* may result if deer removal follows the peak activity period of adult ticks, if the density of ticks per deer increases, or if alternate hosts are parasitized. In a subsequent study, the virtual eradication of deer did reduce tick density (36).

Earlier, the hypothetical reduction in white-footed mouse (*P. leucopus*) populations, the principal reservoir of *B. burgdorferi* (15,17-19) and *Babesia microti* (37), was thought to enhance transmission by a corresponding increase in density of *I. scapularis* larvae and nymphs on the remaining mice (38). Rodent reduction methods were not discussed.

Ecological impacts notwithstanding, the notion that the reduction or elimination of important mammalian hosts provides a viable means of reducing Lyme disease transmission is both scientifically and politically flawed. The first problem with the deer reduction studies is that they were conducted in geographic isolation. Compared to contiguous land masses, islands frequently lack the diversity and abundance of alternate hosts. Aside from the obvious difficulty in implementation, the success of "host management" techniques developed in island situations is not necessarily achievable on its mainland counterpart. While recolonization of an island by most terrestrial mammals will be slow, the niche left following reduction of a local population of deer will be rapidly exploited by surrounding herds. Even if successful, a policy calling for the wholesale destruction of this important game animal can be expected to draw significant opposition from such divergent groups as hunters and animal rights activists.

Habitat Modification

In the management of vector tick populations, habitat modification refers to rendering existing habitats unattractive to hosts while reducing tick survival. The first study involving habitat modification evaluated the effects of mowing and burning vegetation on populations of *I. scapularis* adults (39). Burning reduced adult tick populations by 70.0-88.3%. This reduction persisted for up to one year, but was site-dependent. Mowing resulted in similar reduction (70.0%) for a one year period. The short-term success in the control of *I. scapularis* adults following the destruction of vegetation resulted from an increase in tick mortality due to heat or flame and/or the denial of questing sites. Wilson (39) postulated that the long-term effect of vegetation destruction may have contradictory results by improving deer browse, increasing density of small mammals, and enhancing the ability of subadult ticks to locate potential hosts. More recently, an early April burn reduced the abundance of *I. scapularis* nymphs by 49% after two months compared to the unburned woodlot (40).

In all likelihood, the destruction of vegetation by control burning would be limited to routine forestry management. Legal restrictions against open burning, potential damage to desirable plants and structures, and aesthetics preclude large-scale use of this technique in residential environments, where the majority of transmission is thought to occur. Physical destruction of vegetation holds more promise in residential and recreational areas, primarily through elimination of questing sites along frequently traveled paths. Removal of woodpiles and brushpiles (Photograph 4), stone walls, and other harborages will tend to keep rodent populations to a minimum. The effects of removal of leaf litter on survival of subadult *I. scapularis* warrants investigation.

Biological Control

The degree to which predators and parasites naturally regulate *I. scapularis* abundance has not been established. Spielman (41) reported that the wasp *Hunterellus hookeri* (Hymenoptera: Chalcidae) parasitizes nearly 40% of *I. scapularis* nymphs on Naushon Island, Massachusetts. Although the prevalence of *B. burgdorferi* in ticks from this area is reduced, populations of *I. scapularis* remain significant. Because of its apparent inability to check populations of *I. scapularis* in geographically isolated areas, this chalcid wasp offers little promise as an effective biological control agent on contiguous land masses.

The establishment of flocks of helmeted guinea fowl (*Numida meleagris*) in penned areas reduced populations of *I. scapularis* compared to control areas (42). Since guinea fowl feed on a wide variety of arthropods, it is likely that the impact on non-target organisms will be significant. This, combined with the generally undesirable behavior of guinea fowl renders them of questionable value in most integrated tick management programs.

Acaricide Applications

Tick Survey Techniques

Although it is prudent to survey areas for the presence and abundance of *I. scapularis* before implementing any tick management technique, it is most important when the application of acaricides is anticipated. The presence of ideal habitat is no guarantee that black-legged ticks will be present. The method used to survey the tick population is dependent on both the habitat and the time of year. The various tick survey techniques are discussed in detail by Ginsberg and Ewing (29).

The adult stage of *I. scapularis*, the stage most easily surveyed, is present during the fall, in winter during warm spells, and during the early spring. This stage may be sampled by use of tick drags or walking surveys. Although there may be a number of variations, a tick drag may be fashioned from one square meter of light-colored cotton muslin, corduroy, or similar fabric which is fastened by staples at both ends to 1-meter long dowels. At the forward end of the drag, a 7-foot length of clothesline is attached to either end of the dowel. The loop formed in the rope serves as a handle for pulling the drag through the survey area. When surveying adults, the drag is worked across the shrub layer and the number of ticks adhering to the drag is recorded. The sample is standardized by dragging a measured distance or for a prescribed period of time. An alternative method involves the collection of *I. scapularis* adults through walking surveys. In performing this type of survey, an investigator walks through tick habitat and counts ticks adhering to clothing, rather than on the tick drag. By either method, investigators are cautioned to wear overalls fastened at the cuff to rubber boots with duct tape as personal protective clothing.

Ixodes scapularis subadults are somewhat more difficult to survey. Both stages may be collected using tick drags providing that the shrub layer is sparse. In dense vegetation, a smaller version of the drag, known as a tick flag, is worked across the leaf litter between shrub layer plant stems. Again, the survey may be standardized by flagging a prescribed distance or area. Personal protection against tick exposure may be augmented by use of repellents, since ticks are not collected from investigators' clothing. Nymphs are best surveyed in May or June, while larvae are most abundant in July and August.

The abundance of *I. scapularis* nymphs and larvae may also be determined by trapping hosts, most commonly the white-footed mouse. Depending on the configuration of the site, baited Sherman box traps are set on grids or trap lines overnight. Captured mice (or other suitable hosts) are then anesthetized, examined for ticks, and returned to the site of collection. Ticks removed from the host may be retained in vials containing 70% ethanol for later identification.

Dragging or flagging surveys for subadults in the spring and summer are most productive when conducted during cooler parts of the day, typically midmorning after the dew has dried. Dragging or walking surveys for adults in cooler weather are best performed during midday when temperatures are at their maximum. None of these survey techniques is very productive when vegetation or leaf litter is wet. When repeated surveys of an area are anticipated, they should be further standardized by being conducted at the same time of day and under similar ambient conditions.

Host-Targeted Acaricide Applications

The use of acaricides to control *I. scapularis* has been attempted through two divergent techniques. The first is a host-targeted approach where tubes containing permethrin-treated cotton batting are dispersed in wooded habitats (43). The treated cotton, marketed commercially as Damminix, is intended to be harvested by white-footed mice for nesting material. *Ixodes scapularis* larvae and nymphs exposed to this nesting material subsequently would be controlled. The study showed that 72% of mice in treated areas were free of ticks, compared to only 1% in untreated areas. However, the number of host-seeking *I. scapularis* nymphs were statistically equivalent at treated and untreated sites. Mather and coworkers (43) postulated that acaricide-treated cotton would protect reservoir hosts from *I. scapularis*, thereby reducing transmission of *B. burgdorferi*. One year later, the number of host-seeking nymphs was less than 50% on treated compared to untreated sites, while less than 50% of those collected from treated sites were infected with *B. burgdorferi* (41). In a larger study, 1 of 40 captured *P. leucopus* within treated areas were infested with three ticks, while in untreated sites, 33 of 34 white-footed mice were parasitized by an average of 20 subadult *I. scapularis* per mouse (44).

Independent research conducted in Massachusetts met with similar success (45), while studies in New York (46) and Connecticut (47) have shown no difference in the density of host-seeking *I. scapularis* nymphs or infection rates in the tick in Damminix-treated versus untreated areas. In a long-term study conducted on Long Island, New York, a similar lack of efficacy was demonstrated after three years (48). During one year of that study, a person was more likely to be bitten by an infected tick in Damminix-treated versus untreated sites. While Damminix appeared to reduce the number of subadult ticks on mice, it did little to reduce the risk of exposure to infected host-seeking *I. scapularis* nymphs and adults after two years. These studies suggest that the reduction of *I. scapularis* populations following distribution of Damminix is unpredictable and, at best, may have only limited utility as part of an integrated control program.

Ground Acaricide Applications

The second chemical control approach is more conventional and involves the application of acaricides to tick habitat. The first published study used liquid formulations of carbaryl and diazinon applied via high pressure hydraulic sprayer to wooded areas to control fall populations of *I. scapularis* adults (49). After 72 hours, the population of *I. scapularis* adults was reduced 97.1% in the carbaryl-treated plots and 100% in the diazinon-treated site. As expected, control resulting from these applications were observed the following spring. However, one year after the application, *I. scapularis* population levels in the treated sites were similar to those in the untreated plot. As such, the effectiveness of this single application against adults was limited to one year.

Historically, application of acaricides to control ticks in wooded areas was thought to be impractical because of the inability of sprays to adequately penetrate the vegetation. The control of *I. scapularis* adults provides an exception, since they quest within the shrub layer in the fall following abscission. At this time, *I. scapularis* adults are particularly vulnerable to acaricide sprays. Fall applications, however, have little effect on larvae and nymphs, which are not active at this time. As such, the effectiveness of a single control attempt directed solely against adult ticks in a limited area will be temporary and limited only to that stage. These applications had no demonstrable effects on any life stage of *Amblyomma americanum*, a potential secondary tick vector of *B. burgdorferi* in New Jersey (50).

In recognition of its epidemiological importance in the Lyme disease transmission cycle, several studies were conducted to control *I. scapularis* nymphs during their period of peak activity. Stafford (51) applied two rates of a liquid formulation of carbaryl within a residential area using a high pressure hydraulic sprayer. At 72 hours postapplication, no nymphs were recovered from the treated plots. Control exceeding 90% continued within the treated areas throughout the nymphal activity period. These applications had no apparent effect on the emergence of larvae in the summer or the appearance of adults in the fall.

Owing to problems inherent with getting liquid formulations through growing foliage and into the leaf litter where subadult *I. scapularis* normally quest, Schulze and coworkers (52) applied granular formulations of carbaryl, chlorpyrifos, and diazinon at the highest recommended rates using a chest-mounted Cyclone seeder. Granular acaricide directed against nymphs achieved between 53.8% (diazinon) and 100% (carbaryl) control. A second application against larvae resulted in more uniform, but lower levels of control ranging between 66.3% (chlorpyrifos) and 74.7% (diazinon). Additional applications of carbaryl at reduced rates resulted in proportionately lower levels of control (52). Continuous evaluation of these sites over a two-year period showed a significant reduction in fall populations of *I. scapularis* following treatment against nymphs in all plots and, in some instances, subsequent populations of subadults (53). The degree to which ongoing control was achieved appeared to be correlated with geographic isolation of the treated site from untreated *I. scapularis* habitat.

Applications of several formulations of carbaryl, chlorpyrifos, and cyfluthrin to a large residential community in Westchester County, New York, resulted in significant control of nymphs at all treated sites, ranging from 67.9% to 97.4% (54). Abundance of nymphs at all treated sites remained low throughout the activity period of nymphs, indicating that a well-timed application was sufficient to provide significant control for the nymphal transmission season. Spring applications of liquid and granular formulations of cyfluthrin reduced the abundance of *I. scapularis* by 96% and 97%, respectively, at 10 days postapplication (55).

In 1992, a study was initiated to evaluate the effects of granular carbaryl on populations of *I. scapularis* nymphs in another large hyperendemic residential community. Application of carbaryl granules at the maximum and minimum recommended dosage rates using modified Solo mist blowers resulted in 91.7% and 94.8% control of nymphs, respectively (34).

Although applications of liquid and granular acaricide formulations have demonstrated significant reduction of *I. scapularis* nymphs, the studies were performed in separate areas under different ambient conditions. To test the relative efficacy of these formulations under similar circumstances, maximum recommended rates for liquid and granular carbaryl were applied to wooded residential sites using a low-pressure sprayer and modified Solo mist blower, respectively. Carbaryl applications resulted in significant control of nymphs with both liquid (86.1%) and granular (94.1%) formulations (56). The greater level of control achieved in the Connecticut study (51)compared to the application of liquid carbaryl in New Jersey appeared to be attributable to differences in the high-pressure (Connecticut) versus low-pressure (New Jersey) hydraulic sprayers used. It appears that the higher pressure resulted in greater physical disturbance of the leaf litter, which allowed more acaricide to reach questing *I. scapularis* nymphs. Although comparable levels of control were achieved using liquid carbaryl (51) and carbaryl granules (56), it should be noted that sprays required one-eighth the amount of active ingredient. The apparent environmental benefits of this significantly lower rate of carbaryl, however, may be offset by logistical problems associated with the application of liquid formulations, such as the availability of adequate water supplies, sophisticated equipment, and personnel.

Aerial Acaricide Applications

Although previous research has demonstrated the effectiveness of acaricide sprays against *I. scapularis* adults (49) and nymphs (51,56), and granular formulations against nymphs (34,52), these studies were conducted in relatively circumscribed areas. To test the efficacy of established control measures over potentially larger areas, liquid and granular formulations of carbaryl were aerially applied against *I. scapularis* adults and nymphs, respectively. An aerial application of carbaryl at the recommended rate to a high-use recreational area controlled 93.8% of the fall population of adults after 96 hours (57). Two rates of granular carbaryl were applied by air to dense successional woodland bordering a residential community during the peak activity period of nymphs (34). These applications resulted in 89.6% at the higher rate and 81.1% at the lower rate. The relatively high levels of control achieved with reduced rates of carbaryl were thought to reflect the paucity of leaf litter compared to the sites receiving ground applications of carbaryl.

Aerial applications of liquid and granular acaricide, while effective, require considerable logistical and public relations support. Despite the fact that identical rates are used in ground applications, necessary public notifications, existing public perceptions, and alleged ecological impacts must be addressed with greater urgency when aerial applications are considered. Logistically, procurement of necessary equipment, landing areas, fuel, and weather contraints require more planning and provide more opportunity for delay. Although there are situations where aerial applications are clearly desirable, ground applications have been shown to provide excellent control in a cost-effective manner.

Acaricide Selection

Once the decision has been reached to apply acaricides to a documented tick-infested area, the selection of a particular acaricide must be based on labeling requirements. Of the acaricides currently available for use in this situation, most are labeled for generic tick control. Specific acaricides, formulations, and methods of application may be restricted to certain target areas. Users are cautioned to carefully read the acaricide labeling to ensure that the proposed application is not in violation of federal and State pesticide control laws.

SUMMARY

Although not in the classic sense of combining biological, mechanical, and chemical control techniques, the approach to suppressing *I. scapularis* populations should be an integrated one which employs education, behavioral modifications, some habitat alterations and, as a last resort, the use of acaricides. Avoidance of tick-infested areas and the use of repellents, appropriate clothing, and frequent self-examinations for ticks provide the best means of reducing the risk of Lyme disease. Where avoidance is impractical, chemical control may provide a needed alternative. In most situations, however, acaricides should only be used if avoidance of tick-infested areas is not an option and only after the tick population and the rate of infection have been shown to pose a public health threat. A method of assessing areas for potential risk of Lyme disease transmission has been developed (27).

Review of the published scientific literature suggests that host reduction, habitat modification, biological control, and use of host-targeted acaricides (Damminix) have limited or unpredictable success in reducing black-legged tick populations when used alone. Research conducted in New Jersey and elsewhere has demonstrated the efficacy of properly timed acaricide applications. At present, applications of either liquid acaricides using high-pressure hydraulic sprayers or granular formulations directed against *I. scapularis* nymphs in late May to early June appear to have the greatest impact on the tick population. Single applications have consistently resulted in control of greater than 90% of nymphs and, in some cases, significant reduction in the adult population in the fall and following spring. *Ixodes scapularis* adults are easily controlled by ground or aerial applications of acaricides, but reduction of the adult population does not offer the same public health benefits as the control of nymphs, the life stage responsible for the majority of transmission.

Despite their demonstrated ability to significantly suppress populations of *I. scapularis*, applications of general use acaricides are viewed by some as environmentally unsound. While environmental concerns remain a high priority, such considerations should be balanced against documented threats to public health. The combination of non-chemical techniques and the judicious use of acaricides in an integrated approach provides the most effective means of managing vector tick populations at this time.

Photograph 1. Mixed hardwood forests with a dense shrub layer provide ideal habitat for *Ixodes scapularis*, the principal vector of the Lyme disease spirochete.

Photograph 2. Abandoned fields in secondary woody succession and ecotonal areas may also provide suitable habitats for *Ixodes scapularis*.

Photograph 3. Landscaping and ornamental plantings around the home may serve as habitat for *Ixodes scapularis*. Low numbers of ticks may also be found in lawns immediately adjacent to landscaped and wooded areas.

Photograph 4. Woodpiles and brush piles provide harborage and nesting sites for mammalian hosts of *Ixodes scapularis*, such as mice and chipmunks.

LITERATURE CITED

1. Oliver, J.H., Jr., M.R. Owsley, H.J. Hutcheson, A.M. James, C. Chen, W.S. Irby, E.M. Dotson & D.K. McLain. 1993. Conspecificity of the ticks *Ixodes scapularis* and *I. dammini* (Acari: Ixodidae). J. Med. Entomol. 30:54-63.

2. Piesman, J., T.N. Mather, R.J. Sinsky & A. Spielman. 1987. Duration of tick attachment and *Borrelia burgdorferi* transmission. J. Clin. Microbiol. 25:557-558.

3. Schulze, T.L., W.E. Parkin & E.M. Bosler. 1988. Vector tick populations and Lyme disease: A summary of control strategies. Ann. N.Y. Acad. Sci. 539:204-211.

4. Schulze, T.L., G.S. Bowen, M.F. Lakat, W.E. Parkin & J.K. Shisler. 1985. The role of adult *Ixodes dammini* (Acari: Ixodidae) in the transmission of Lyme disease in New Jersey, USA. J. Med. Entomol. 22:88-93.

5. Schulze, T.L., G.S. Bowen, M.F. Lakat, W.E. Parkin & J.K. Shisler. 1986. Seasonal abundance and host utilization of *Ixodes dammini* (Acari:Ixodidae) and other ixodid ticks from an endemic Lyme disease focus in New Jersey, USA. J. Med. Entomol. 23:105-109.

6. Schulze, T.L., J.K. Shisler, M.F. Lakat & W.E. Parkin. 1986. Evolution of a focus of Lyme disease. Zbl. Bakt. Hyg. A 263, 65-71.

7. Schulze, T.L., M.F. Lakat, G.S. Bowen, W.E. Parkin & J.K. Shisler. 1984. *Ixodes dammini* (Acari: Ixodidae) and associated ixodid ticks collected from white-tailed deer in New Jersey, USA: Geographical distribution and relation to selected environmental and physical parameters. J. Med. Entomol. 21:741-749.

8. Schulze, T.L., E.M. Bosler, J.K. Shisler, I.C. Ware, M.F. Lakat & W.E. Parkin. 1986. Prevalence of canine Lyme disease from an endemic area as determined by serosurvey. Zbl. Bakt. Hyg. A 263, 427-434.

9. Cohen, D.P., E.M. Bosler, W. Bernard, D. Meirs, R. Eisner & T.L. Schulze. 1988. Epidemiological studies of Lyme disease in horses. Ann. N.Y. Acad. Sci. 539:244-257.

10. Anderson, J.F. 1988. Mammalian and avian reservoirs for *Borrelia burgdorferi*. Ann. N.Y. Acad. Sci. 539:180-191.

11. Battaly, G.R. & D. Fish. 1993. Relative importance of bird species as hosts for immature *Ixodes dammini* (Acari: Ixodidae) in a suburban residential landscape in southern New York State. J. Med. Entomol. 30:740-747.

12. Bosler, E.M., B.G. Ormiston, J.L. Coleman, J.P. Hanrahan, & J.L. Benach. 1984. Prevalence of the Lyme disease spirochete in populations of white-tailed deer and white-footed mice. Yale J. Biol. Med. 57:201-209.

13. Telford, S.R. III, T.N. Mather, S.I. Moore, M.L. Wilson & A. Spielman. 1988. Incompetence of deer as reservoirs of *Borrelia burgdorferi*. Ann. N.Y. Acad. Sci. 429-430.

14. Anderson, J.F., L.A. Magnarelli, W. Burgdorfer & A.G. Barbour. 1983. Spirochetes in *Ixodes dammini* and mammals from Connecticut. Am. J. Trop. Med. Hyg. 32:818-824.

15. Bosler, E.M., J.L. Coleman, J.L. Benach, D.A. Massey, J.P. Hanrahan, W. Burgdorfer & A.G. Barbour. 1983. Natural distribution of the *Ixodes dammini* spirochete. Science 220:321-322.

16. Anderson, J.F. and L.A. Magnarelli. 1984. Avian and mammalian hosts for spirochete-infected ticks and insects in a Lyme disease focus in Connecticut. Yale J. Biol. Med. 57:177-191.

17. Spielman, A., J.F. Levine & M.L. Wilson. 1984. Vectorial capacity of North American *Ixodes* ticks. Yale J. Biol. Med. 57:507-513.

18. Levine, J.F., M.L. Wilson & A. Spielman. 1985. Mice as reservoirs of the Lyme disease spirochete. Am. J. Trop. Med. Hyg. 34:355-360.

19. Donahue, J.G., J. Piesman & A. Spielman. 1987. Reservoir competence of white-footed mice for Lyme disease spirochetes. Am. J. Trop. Med. Hyg. 36:92-96.

20. Schulze, T.L., M.F. Lakat, W.E. Parkin, J.K. Shisler, D.J. Charette & E.M. Bosler. 1986. Comparison of rates of infection by the Lyme disease spirochete in selected populations of *Ixodes dammini* and *Amblyomma americanum* (Acari: Ixodidae). Zbl. Bakt. Hyg. A 263, 72-78.

21. Magnarelli, L.A., J.F. Anderson & D. Fish. 1987. Transovarial transmission of *Borrelia burgdorferi* in *Ixodes dammini* (Acari: Ixodidae). J. Infect. Dis. 234-236.

22. Carey, A.B., W.L. Krinsky & A.J. Main. 1980. *Ixodes dammini* (Acari: Ixodidae) and associated ixodid ticks in south-central Connecticut, USA. J. Med. Entomol. 17:89-99.

23. Carey, M.G., A.B. Carey, A.J. Main, W.L. Krinsky & H.E. Sprance. 1981. *Ixodes dammini* (Acari: Ixodidae) in forests in Connecticut. J. Med. Entomol. 18:175-176.

24. Daniels, T.J., D. Fish & R.C. Falco. 1989. Seasonal activity and survival of adult *Ixodes dammini* (Acari: Ixodidae) in southern New York State. J. Med. Entomol. 26:610-614.

25. Falco, R.C. & D. Fish. 1988. Prevalence of *Ixodes dammini* near the homes of Lyme disease patients in Westchester County, New York. Am. J. Epidemiol. 127:826-830.

26. Lastavica, C.C., M.L. Wilson, V.P. Berardi, A. Spielman & R.D. Deblinger. 1989. Rapid emergence of a focal epidemic of Lyme disease in coastal Massachusetts. N. Engl. J. Med. 320:133-137.

27. Schulze, T.L., R.C. Taylor, G.C. Taylor & E.M. Bosler. 1991. Lyme Disease: A proposed ecological index to assess areas of risk in the northeastern United States. Am. J. Public Health. 81:714-718.

28. Wilson, M.L., A.M. Ducey, T.S. Litwin, T.A. Gavin & A. Spielman. 1990. Microgeographic distribution of immature *Ixodes dammini* ticks correlated with that of deer. Med. Vet. Entomol. 4:151-159.

29. Ginsberg, H.S. & C.P. Ewing. 1989. Comparison of flagging, walking, trapping, and collecting ticks from hosts as sampling methods for northern deer ticks, *Ixodes dammini*, and lone-star ticks, *Amblyomma americanum* (Acari: Ixodidae). Exp. Appl. Acarol. 7:313-322.

30. Maupin, G.O., D. Fish, J. Zultowsky, E.G. Campos & J. Piesman. 1991. Landscape ecology of Lyme disease in a residential area in Westchester County, New York. Am. J. Epidemiol. 133:1105-1113.

31. Carroll, M.C., H.S. Ginsberg, K.E. Hyland & R. Hu. 1992. Distribution of *Ixodes dammini* (Acari: Ixodidae) in residential lawns on Prudence Island, Rhode Island. J. Med. Entomol. 29:1052-1055.

32. Hanrahan, J.P., J.L. Benach, J.L. Coleman, E.M. Bosler, D.L. Morse, D.J. Cameron, R. Edelman & R.A. Kaslow. 1984. Incidence and cumulative frequency of endemic Lyme disease in a community. J. Infect. Dis. 150:489-496.

33. Falco, R.C. & D. Fish. 1988. Ticks parasitizing humans in a Lyme disease endemic area of southern New York State. Am. J. Epidemiol. 128:1146-1152.

34. Schulze, T.L., R.A. Jordan, L.M. Vasvary, M.S. Chomsky, D.C. Shaw, M.A. Meddis, R.C. Taylor & J. Piesman. Suppression of *Ixodes*

scapularis (Acari: Ixodidae) nymphs in a large residential community. J. Med. Entomol. 31:206-211.

35. Wilson, M.L., J.F. Levine & A. Spielman. 1984. Effect of deer reduction on abundance of the deer tick (*Ixodes dammini*). Yale J. Biol. Med. 57:697-705.

36. Wilson, M.L., S.R. Telford III, J. Piesman & A. Spielman. 1988. Reduced abundance of immature *Ixodes dammini* (Acari: Ixodidae) following removal of deer. J. Med. Entomol. 25:224-228.

37. Spielman, A., C.M. Clifford, J. Piesman & M.D. Corwin. 1979. Human babesiosis on Nantucket Island, USA: description of the vector *Ixodes (Ixodes) dammini*, n. sp. (Acarina: Ixodidae). J. Med. Entomol. 15:218-234.

38. Spielman, A., M.L. Wilson, J.F. Levine & J. Piesman. 1985. Ecology of *Ixodes dammini*-borne human babesiosis and Lyme disease. Ann. Rev. Entomol. 30:439-460.

39. Wilson, M.H. 1986. Reduced abundance of adult *Ixodes dammini* (Acari: Ixodidae) following destruction of vegetation. J. Econ. Entomol. 79:693-696.

40. Mather, T.N., D.C. Duffy & S.R. Campbell. 1993. An unexpected result from burning vegetation to reduce Lyme disease transmission risks. J. Med. Entomol. 30:642-645.

41. Spielman, A. 1988. Prospects for suppressing transmission of Lyme disease. Ann. N.Y. Acad. Sci. 539:212-220.

42. Duffy, D.C., R. Downer & C. Brinkley. 1992. The effectiveness of helmeted guineafowl in the control of the deer tick, the vector of Lyme disease. Wilson Bull. 104:342-345.

43. Mather, T.N., J.M.C. Ribiero & A. Spielman. 1987. Lyme disease and babesiosis: Acaricide focused on potentially infected ticks. Am. J. Trop. Med. Hyg. 36:609-614.

44. Mather, T.N., J.M.C. Ribiero, S.I. Moore & A. Spielman. 1988. Reducing transmission of Lyme disease spirochetes in a suburban setting. Ann. N.Y. Acad. Sci. 539:402-403.

45. Deblinger, R.D. & D.W. Rimmer. 1991. Efficacy of a permethrin-based acaricide to reduce the abundance of *Ixodes dammini* (Acari: Ixodidae). J. Med. Entomol. 28:708-711.

46. Daniels, T.J., D. Fish & R.C. Falco. 1991. Evaluation of host-targeted acaricide for reducing risk of Lyme disease in southern New York State. J. Med. Entomol. 28:537-543.

47. Stafford, K.C. III. 1991. Effectiveness of host-targeted permethrin in the control of *Ixodes dammini* (Acari: Ixodidae). J. Med. Entomol. 28:611-617.

48. Bosler, E.M., J.G. Daley, J.D. Schwender, J.A. Gabbia & T.L. chulze. 1992. Host-targeted tick abatement and medium-sized mammals in the transmission of Lyme disease. V International Conference on Lyme Borreliosis. Abstract No. 270 (invited presentation). Arlington, Va.

49. Schulze, T.L., W.M. McDevitt, W.E. Parkin & J.K. Shisler. 1987. Effectiveness of two insecticides in controlling *Ixodes dammini* (Acari: Ixodidae) following an outbreak of Lyme disease in New Jersey. J. Med. Entomol. 24:420-424.

50. Schulze, T.L., G.S. Bowen, E.M. Bosler, M.F. Lakat, W.E. Parkin, R. Altman, B.G. Ormiston & J.K. Shisler. 1984. *Amblyomma americanum*: A potential vector of Lyme disease in New Jersey. Science 224:601-603.

51. Stafford, K.C. III. 1991. Effectiveness of carbaryl applications for the control of *Ixodes dammini* nymphs in an endemic residential area. J. Med. Entomol. 28:32-36.

52. Schulze, T.L., G.C. Taylor, E.M. Bosler, R.A. Jordan & J.K. Shisler. 1991. Effectiveness of

selected granular acaricide formulations in suppressing populations of *Ixodes dammini* (Acari: Ixodidae): I. Short-term control of nymphs and larvae. J. Med. Entomol. 28:624-629.

53. Schulze, T.L., R.A. Jordan, G.C. Taylor & E.M. Bosler. The potential for long-term suppression of *Ixodes scapularis* (Acari: Ixodidae) populations following single applications of granular acaricides against subadults. (submitted for publication).

54. Curran, K.L., D. Fish & J. Piesman. 1993. Reduction of nymphal *Ixodes dammini* (Acari: Ixodidae) in a residential suburban landscape by area application of insecticides. J. Med. Entomol. 30:107-113.

55. Solberg, V.B., K. Neidhardt, M.R. Sardelis, F.J. Hoffmann, R. Stevenson, L.R. Boobar & H.J. Harlan. 1992. Field evaluation of two formulations of cyfluthrin for control of *Ixodes dammini* and *Amblyomma americanum* (Acari: Ixodidae). J. Med. Entomol. 29:634-638.

56. Schulze, T.L., R.A. Jordan, L.M. Vasvary, M.S. Chomsky, D.C. Shaw, R.C. Taylor & J. Piesman. Comparison of liquid and granular formulations of carbaryl in controlling *Ixodes scapularis* (Acari: Ixodidae) nymphs in a residential setting. (submitted for publication).

57. Schulze, T.L., G.C. Taylor, L.M. Vasvary & R.A. Jordan. 1992. Effectiveness of an aerial application of carbaryl in controlling *Ixodes dammini* (Acari: Ixodidae) adults in a high-use recreational area in New Jersey. J. Med. Entomol. 29:544-547.

$2.00

This work was funded in part by Cooperative Agreement U50/CCU206567-04 from the Centers for Disease Control and Prevention.

This publication has been prepared by Rutgers Cooperative Extension in cooperation with the New Jersey Department of Health and the Freehold (N.J.) Area Health Department.

Information in this bulletin appears with the understanding that no discrimination is intended and no endorsement by Rutgers Cooperative Extension is implied.

Desktop publishing by the Cook College/NJAES Office of Communications and Public Affairs

RUTGERS COOPERATIVE EXTENSION
N.J. AGRICULTURAL EXPERIMENT STATION
RUTGERS, THE STATE UNIVERSITY OF NEW JERSEY
NEW BRUNSWICK