SHORT COMMUNICATION

Winter Activity of *Ixodes scapularis* (Acari: Ixodidae) and the Operation of Deer-Targeted Tick Control Devices in Maryland

J. F. CARROLL[1] AND M. KRAMER[2]

United States Department of Agriculture, Agricultural Research Service, Animal and Natural Resources Institute, Parasite Biology, Epidemiology and Systematics Laboratory

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ABSTRACT Host-seeking activity of adult blacklegged ticks, *Ixodes scapularis* Say was monitored by flagging during winter months in Beltsville, MD. Ticks were active many days during January and February, the coldest months, with some captures made when there was 70% snow cover and temperatures as low as −2°C. Substantial numbers (70–90 ticks/h of flagging) of adult *I. scapularis* were captured on favorable days in January and February. The cost to treat white-tailed deer, *Odocoileus virginianus* (Zimmermann), using '4-poster' deer self-treatment devices, was estimated on a per female tick basis. We estimated deer abundance and tick attachment rates using data from the literature, tick activity levels using weather data and drag counts of ticks, and costs to operate the devices from experience. We found that self-treatment devices need not be operated continuously from late December until the third week of February. On average, savings of half the operating costs would be realized by not operating the devices when tick activity was low.

KEY WORDS weather, '4-poster', model, blacklegged tick, white-tailed deer

DEER SELF-TREATMENT DEVICES are a promising technology for controlling populations of blacklegged ticks, *Ixodes scapularis* Say, (Pound et al. 2000), the principal vector of the agent causing Lyme disease in the central and eastern U.S. (Spielman et al. 1985). The preponderance of adult *I. scapularis* feed on white-tailed deer, *Odocoileus virginianus* (Zimmermann), and population densities of *I. scapularis* are correlated with deer numbers (Wilson et al. 1985, 1988). As deer feed on corn bait at '4-poster' self- treatment devices, they rub against acaricide-impregnated paint rollers, applying the acaricide to their ears, head and neck (Pound et al. 2000).

Relative humidity, temperature, light have been demonstrated to influence the vertical migration on vegetation and questing by ticks (Milne 1950, Lees and Milne 1951, Rechav 1979, Loye and Lane 1988, Harlan and Foster 1990, Lane et al. 1995, Schulze et al. 2001). Although adult *I. scapularis* tend to be active during cooler months, their host-seeking activity is influenced by ambient temperature (Daniels et al. 1989, Duffy and Campbell 1994, Clark 1995). In the laboratory, adult *I. scapularis* lost coordination when temperatures were below 8°C, and below 4°C they become inactive (Clark 1995). In the field, in Westchester County and on Long Island, NY, adult *I. scapularis* followed a similar pattern of reduced host-seeking activity, as manifested in lower drag counts with declining temperatures (Daniels et al. 1989, Duffy and Campbell 1994). Maryland is the southernmost of those eastern states with high incidences of Lyme disease (Spielman et al. 1985), and it has the mildest winter weather. In Maryland adult *I. scapularis* begin seeking hosts in October. By November high numbers of host-seeking adults can be found, and ticks of that cohort survive through the winter until late spring (Carroll and Schmidtmann 1996), although some mortality is inevitable (Daniels et al. 1989). An uncritical glance at the average monthly temperatures for central Maryland gives the impression that January and February are largely unsuitable for *I. scapularis* activity. However, in Maryland, New Jersey, and further north, on many days during the winter the temperature during part of the day permits *I. scapularis* activity as manifested by their capture on drag cloths (Duffy and Campbell 1994, Schulze et al. 2001).

An important consideration in developing a program using deer self-treatment devices to control *I. scapularis* is when to operate the devices. There are costs in labor, equipment, maintenance, bait, and acaricide in the operation of the devices, so it is wasteful to maintain them when ticks are not active. The purposes of this study were to ascertain the relative activity of adult *I. scapularis* activity in central Maryland during winter, estimate the costs associated with operating the devices under various scenarios, and develop recommendations for winter use of deer self-treatment devices.

[1] E-mail: jcarroll@anri.barc.usda.gov.

[2] United States Department of Agriculture, Agricultural Research Service, Biometrics, Beltsville, Maryland 20705.

Materials and Methods

Sampling. Host-seeking activity of *I. scapularis* adults was monitored by flagging with a 0.5 by 0.5 m white flannel cloth at three sites (the third site was added on the third sample date) at the U.S. Department of Agriculture, Beltsville Agricultural Research Center (BARC), Beltsville, Prince George's County, MD. Each site was flagged while the flagger walked slowly for 20 min along a prescribed route that meandered back and forth between forest and ecotones that bordered dirt roads or cultivated fields. The forests were primarily of a mixed deciduous nature dominated by oaks, *Quercus* spp., red maple, *Acer rubrum,* and tulip tree, *Liriodendron tulipifera,* with patches of Virginia pine, *Pinus virginiana.* The forest understory and the ecotone were characterized by abundant greenbrier, *Smilax* sp. The routes were 600–700 m in length, and 0.6–1.1 km from the periphery of an area where '4-posters' were operated under experimental conditions. By flip-flopping the flag during sampling the flagger was able to detect adult *I. scapularis* on the flag almost as soon as they were acquired. The pant legs of the flagger were visually checked for ticks about every 30 s. Captured ticks were counted and removed from the flag and clothing, and released along the route just passed. Routes were flagged two or three times per month from January through April, 2000, and from November, 2000, through April, 2001 except when precipitation, continuous snow cover, or low temperatures ($<-5°C$) occurred.

Models. We developed two models, the first to estimate tick activity using weather data and the flag counts, and the second to estimate the costs on a per female tick basis using a variety of variables, including predictions from the first model.

Temperature, precipitation, insolation, wind velocity and relative humidity were recorded at 15 min intervals at an official weather station at BARC ≈0.6–0.8 km from the flagging sites. Temperatures were also recorded at each site immediately after flagging for most sampling dates. Stepwise regressions using the *R* statistical package (Free Software Foundation, Boston, MA, http://www.gnu.org) were constructed to predict the square root of the total number of ticks found in winter months using site temperature and weather station data. Because the focus of this study was on predicting tick winter activity (when '4 posters' may not need to be continuously operated), the 13 sampling dates ($n = 37$ 20-min samples) in December, January, and February were used to develop the model. Adding fall and spring dates, when counts are typically much higher, would have forced the model to also accommodate those points, potentially creating a more complicated model and reducing the fit to winter dates because the relationship between tick activity and weather variables may differ from season to season. The square-root transformation was used because other studies (e.g., Carroll and Kramer 2001) have shown that tick captures in this area follow a Poisson distribution. Because no sampling occurred during precipitation or when vegetation was visibly wet, because ticks are infrequently captured in wet conditions (Atwood and Sonenshine 1967), our modeling ignores precipitation effects. In general, tick abundance, as measured by flagging, is well predicted by winter weather (Duffy and Campbell 1994). We determined that site temperatures were not better than station temperatures for prediction, nor were the 15 min weather data better than daily averages. Thus, we used daily average weather station data on both the day of sampling and prior day for the regression model. Because there were some differences among the predicted values for the three individual sites, we used their average for our predicted tick abundance.

While data from nonwinter months were not used in modeling, we present March and April data for comparisons to winter tick activity. There were 18 samples on six dates taken in March and 21 samples on seven dates taken in April. Historical winter data from this weather station from 1996 to 2000 were used to describe weather trends for the period from December through March that could influence tick activity and '4-poster' operation.

To estimate the cost of treating deer for ticks, we calculated the cost on a per tick treated basis. For this, we needed to estimate the number of deer using the self-treatment device, how many ticks were finding hosts on any given day, and the cost of maintaining the devices. While we were able to calculate point estimates for these variables, it was not possible to calculate variances for any except tick abundance (for which we have an estimate of the variance from the regression model). Instead, we calculated estimates under various scenarios, to try to estimate costs at the limits of what we considered reasonable values for the BARC sites. For each parameter, we used a "low," "medium," and "high" estimate, as explained below. Another assumption we made was that the treatment is 100% effective. The device treats the head and neck (where most ticks attach [Schmidtmann et al. 1998]) effectively, but acaricide can only be transferred to other areas by grooming. The duration of full efficacy of the acaricide was assumed to be 1 wk.

We estimated the number of deer using a '4-poster' device at Beltsville (d in the model below), by estimating how much corn is consumed and how many deer are consuming the corn. Results from studying Texas deer (Pound et al. 1996) indicate that a 45 kg deer will consume ≈0.45 kg of corn/d. Because ≈18 kg of corn was used per week, a "medium" estimate for the number of deer using a device is 5.7. We used a "low" estimate of 2.9, corresponding to a deer eating 0.9 kg of corn/d, and a "high" estimate of 11.4, corresponding to deer eating only 0.23 kg of corn/d.

We estimated how many ticks attached to a deer on a given day based on the predicted tick activity. Using the number of ticks found on deer by Schmidtmann et al. (1998) in Beltsville and Laurel, MD (on average 42 male and female ticks), and the ≈7 d it takes for a female to complete a meal, we estimated that ≈3 female ticks attach to a deer on a winter day when conditions are optimal for ticks. Thus, we linked three ticks ("medium" estimate) to the highest number we

found from sampling, 54. Our "low" and "high" estimates were 1.5 and 7, respectively. The estimate of the number of female ticks attaching per deer on a given day is then $t = \hat{y} * a/54$, where $\hat{y}$ is the square of the prediction of tick abundance from the regression equation, and a is 1.5, 3, or 7. Values of the regression prediction <0 (typically cold days) were set to 0, before squaring. These values corresponded to days when treatment was not necessary. This expression also produced values larger than a, because $\hat{y}$ could be >54. These values correspond to days with high levels of predicted tick activity, days when one would certainly want to treat deer.

Costs to maintain a '4-poster' include the costs of labor, corn, acaricide, equipment maintenance and replacement, fuel, handling, and storage. For the Beltsville '4-poster' sites, we estimated that ARS would pay about $20 per device per week ("medium" estimate) if this work were contracted out to a local government agency or private company (parameter c below). Our "low" and "high" estimates were $10 and $30 per week, divided by seven in the equation below to yield a daily estimate.

The cost per tick can then be calculated as $t^{-1}\ d^{-1}\ c/7$. In units, this is (ticks/[day*deer])$^{-1}$ (deer/feeder)$^{-1}$ (cost [$]/[feeder*wk]) (wk/7 d). We calculated costs for 27 scenarios (three parameters, three levels each) for the 148 winter days corresponding to the sampling period (1/00, 2/00, 12/00, 1/01, 2/01). Once days requiring '4 poster' operation (treatment) were identified, a calendar was used to determine how many weeks the '4 poster' would be operated such that every treatment day was covered, with treatment starting on the first day needing it and not covered by the previous treatment. We ignored the effects of holiday and weekends; in practice devices might not be serviced until the next business day.

Results

Adult *I. scapularis* were found on all flagging dates, including the coldest sampling date (22 February 2001) when the temperature was −2.2°C during flagging. Ticks of both sexes were about equally represented in capture totals (237 males, 214 females during January and February, the period used in model, see Table 2 for capture totals by date). Twenty ticks were captured on two sampling routes, when snow covered as much as an estimated 70% of the ground. On the next two sampling dates, when temperatures were similar but no snow was present, 2–3 times more ticks were captured on these same two routes. The level of tick activity in January and the first half of February was irregular (Table 1). As many as 90 adult ticks were captured in 1 h of flagging the three sampling routes on one date in February, and 74 ticks were captured in 40 min of flagging two routes on one date in January. March is typically a high activity month for adult *I. scapularis* in central Maryland. In March, 2000, an average of 88.3 ± 4.6 (SEM), $n = 4$, adult *I. scapularis* was captured per sampling date (totals for all three sites), and an average of 22.0 ± 9.1 (SEM), $n = 3$, ticks was captured per sampling date in March 2001 (Table 2). In general, for all months, more ticks were captured on each flagging route in 2000 than in 2001. On the two warmest (>22°C during flagging) sample dates, both in April, captures were much lower than the immediately preceding dates (Table 2), which were cooler (≤15°C). Each year by mid-April, attrition of the adult cohorts was manifested in generally fewer captures.

Through modeling we found that tick activity was related to many weather variables. Mount et al. (1997) modeled adult tick host seeking activity as a quadratic function of temperature alone, with zeros at −0.3 and 20.3°C. The final model we used included a site variable (allowing one site to differ in intercept from the other two), the prior day's average temperature, and two current day variables, average solar radiation and minimum relative humidity. The R^2 value was 0.82 and diagnostics indicated no systematic problems with the regression model. The regression model we used was not unique for providing a good fit to the data, but we preferred it because it was relatively simple, produced reasonable estimates of tick activity for nonsampled

Table 1. Total numbers of adult *I. scapularis* captured by flagging in December–February, 2000–2001

	Males	Females	Total
December 12, 2000	2	4	6
January 4, 2000[a]	37	37	74
12, 2001	2	1	3
17, 2001	8	5	13
26, 2001	0	2	2
31, 2001	10	15	25
February 11, 2000[a]	10	10	20
17, 2000	31	22	53
22, 2000	52	26	78
8, 2001	17	16	33
22, 2001	1	0	1
27, 2001[b]	28	25	53
28, 2000	38	52	90

[a] Two sites only were sampled on these dates, three sites were sampled on all other dates.
[b] Highest total for 2001.

Table 2. Total numbers of adult *I. scapularis* captured by flagging in March and April, 2000–2001. Activity was sufficiently high to warrant continuous operation of deer self-treatment devices in both months. Attrition of the adult cohort is evident for April

	Males	Females	Total
March 10, 2000	46	40	86
15, 2000	42	40	82
19, 2000	24	29	53
25, 2000[a]	59	38	97
8, 2001	18	15	33
20, 2001	12	17	29
27, 2001	2	2	4
April 7, 2000	7	13	20[b]
12, 2000	28	23	51
19, 2000	24	29	53
2, 2001	16	18	34
10, 2001	26	16	42
18, 2001	7	11	18
27, 2001	1	1	2[b]

[a] Highest total for 2000.
[b] The two warmest days during sampling (>22°C).

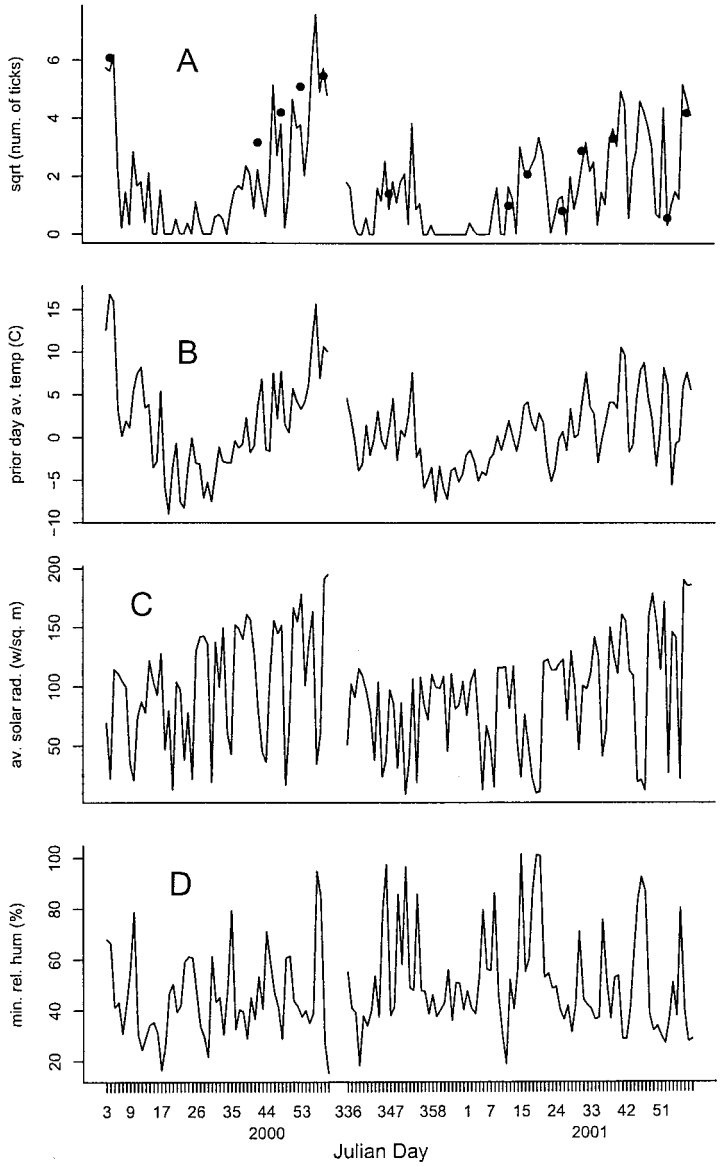

Fig. 1. Winter tick activity (panel A) and independent weather variables (panel B, previous day temperature; panel C, average solar radiation; panel D, minimum relative humidity) for the prediction period (1/00, 2/00, 12/00, 1/01, 2/01). Superimposed on the predictions in panel A are averages of the square roots of observed counts of ticks (dots). See the text for the regression coefficients and other details.

dates, and was readily interpretable from a biological perspective. Other models (Mount et al. 1997, Duffy and Campbell 1994) gave similar good predictions of tick captures in winter. The regression model we used is

$$\sqrt{(\hat{y})} = -5.324 + 1.067\, s_1 + 0.315\, t_p + 0.0284\, r + 0.0702\, h,$$

where $\hat{y}$ is the predicted number of ticks, $s_1 = 1$ if the sample came from site one and $s_1 = 0$ otherwise, t_p is the average temperature (C) of the previous day, r is the average solar radiation (w/m^2), and h is the minimum relative humidity (%). A line plot of predicted values of tick activity (square root of the number of ticks) for the entire prediction period is given in Fig. 1a. Superimposed are sample averages (as dots) of the square roots of the numbers of ticks collected for the three sites (only two sites were sampled on two of the dates). Figure 1b–d shows line plots of the three predictor weather variables for the prediction period. Because all the coefficients are positive, predicted tick activity (Fig. 1a) is a weighted sum of the values of these three weather variables, with negative values set to zero.

Table 3. Average number of days (±1 SEM) per week with (1) an average temperature above (top table), or (2) at least reaching (bottom table) the activity threshold (4°C) of adult *I. scapularis*, 1996–2000, at Weather Station 3 at the Beltsville Agricultural Research Center, Beltsville, MD

	Days the average temperature was above threshold			
	1st wk	2nd wk	Penultimate week	Final week
January	2.8 ± 0.3	1.6 ± 0.6	2.0 ± 0.6	0.8 ± 0.3
February	1.2 ± 0.6	1.4 ± 0.5	3.0 ± 0.6	5.4 ± 1.0
	Days when the threshold was reached			
January	4.2 ± 1.2	3.4 ± 1.0	3.8 ± 1.0	3.6 ± 1.0
February	3.6 ± 1.1	4.2 ± 1.0	5.6 ± 0.6	6.2 ± 0.7

We present results of estimating costs in two ways: (1) treatment is only administered if the cost per female tick is less than $1.00, and (2) treatment is administered if the estimated number of female ticks attaching per day is >0.25, i.e., days when deer are more likely to pick up ticks.

For treating only when costs fall below $1.00/female tick, "medium" parameter estimates yielded 22 out of the 148 d for treatment, requiring operation for eight of the 22 wk, and with a savings of $280 per '4-poster' (versus maintaining the device throughout the 22 wk). Under the most expensive scenario (with the fewest deer using the device), operation was necessary only for 1 d (1 wk). For the least expensive scenario, operation would occur on 83 d (in 18 wk). Note that, under these different scenarios, treatments also start at different attachment rates. One does not start treating in the most expensive scenario until the predicted attachment rate is very high.

If self-treatment devices were provisioned only when predicted female tick attachment rates were >0.25 ticks/d, we found that devices should be run on 47 d (requiring 14 wk of operation). The average cost per tick was $0.87 (medium estimates on all parameters), $0.13 (lowest), and $3.17 (highest). Thus, there can be a large cost benefit to only operating devices when ticks are active, and the more expensive the cost is per tick, the larger the benefit.

Temperature is one of the three variables important in predicting tick activity. Taken in a historical context (the recent winters of 1996–2000) temperature data provide some insight about when continuous operation of deer self-treatment devices could cease for winter and when it could resume (Table 3). According to data recorded at the BARC weather station from 1996 to 2000, an average of 11.3 ± 1.8 (SEM) d in December had an average temperature above the adult *I. scapularis* activity threshold, and 24.8 ± 0.7 (SEM) d when the maximum daily temperature exceeded the activity threshold. In central Maryland continuous operation of deer self-treatment devices is probably necessary for the first three weeks in December. In January and the first half of February tick activity was irregular, and historical data (1996–2000) show that there can be 2-wk periods during which temperatures remained below adult *I. scapularis* activity thresholds. However, no specific 2-wk period (e.g., third and fourth wk of January) was consistently free of above threshold days during 1996–2000. The average number of days when maximum daily temperatures reached or exceeded the tick activity threshold in January and February, 1996–2000, by week, are shown in Table 3, as are the average number of days per week when the average temperature each day reached the activity threshold. During the penultimate and last weeks of February (1996–2000) an average of 3.0 ± 0.6 (SEM) and 5.4 ± 1.0 (SEM) d/wk, respectively, had an average temperature above the adult *I. scapularis* activity threshold.

Discussion

It seems likely that in Maryland engorged female *I. scapularis* falling from hosts in January and February have at least a moderate chance of surviving. The survival of fed females that drop from deer in winter may depend greatly on the ability of the tick to crawl into leaf litter. Most (64–70%) engorged female *I. scapularis* placed in leaf litter in Maryland in February survived to oviposit in the spring (Carroll 1996). However, fed *Dermacentor albipictis* (Packard) that dropped from hosts in snow in Canada were eaten by birds (Addison et al. 1989). In Maryland extensive snow cover usually does not last more than a few days. Thus, there is probably reason to be concerned about winter-feeding *I. scapularis* contributing to tick populations in Maryland.

The microenvironment of a tick can vary greatly within 1 m^3, and over short periods of time (Harlan and Foster 1990). For example, the temperature differential can be great between the leaf litter and the tip of a blade of grass, in the shade or in direct sun. In spite of this, the much coarser weather station data appeared adequate for modeling tick activity. Weather station data were also more complete because variables other than temperature were available.

Prior day's average temperature may be a better predictor than current day's average temperature because of the arbitrariness of when a 24 h period begins. Ticks had not yet experienced much of the "current" day's temperature, because sampling occurred about half-way through the current day's 24 h period. It is possible that predictions would improve if averages for 24 h periods starting at a time other than 12:00 a.m. were used, or if averages were based on a period smaller or >24 h with the weighting of the hours allowed to differ. The quantity of solar radiation may greatly influence the microclimate experienced by a tick, as would the relative humidity because ticks are sensitive to desiccation, so the predictive ability of these variables makes biological sense.

The modeling of tick activity is site dependent, because it depends on local weather patterns and local tick abundance. For the Beltsville area, many of the models predicting tick activity we generated using stepwise regression under different criteria could have been used to develop the cost model. The independent variables selected changed depending on which months of the study were included and how

complex the model was allowed to grow; the variables we used were those chosen when only winter months were modeled and complexity greatly restricted. Winter weather conditions also vary geographically and year-to-year, so local weather data should be used to develop a tick activity model for specific locations. The result we want to emphasize is that local tick activity can be predicted well by local weather variables, not that our model must be used. Thus, decisions on when to operate feeders can be made without resorting to sampling ticks, once the relationship between local tick activity and weather has been established for a given area.

White-tailed deer are crepuscular/nocturnal in their foraging activities, when temperatures drop. Durden et al. (1996) found that host-seeking *I. scapularis* quest nocturnally as well as during the day. However, even on warm days in January and February, nighttime temperatures can fall below tick activity thresholds. Thus, a high level of activity in host-seeking adult *I. scapularis* during mid afternoon in winter may not be indicative of the numbers of ticks that are active when deer are most active. Warming diurnal temperatures may cause ticks in leaf litter to ascend vegetation, placing them in position to contact and catch hold of passing deer even though the ticks lack full mobility.

The best strategy to control ticks in winter will depend on the goal (degree of tick control desired) and funds available. Even under the lowest cost scenario, controlling ticks on deer at BARC is sufficiently costly that it is worthwhile to know when it is not necessary to operate the devices. Thus, the tick activity model, flagging data, and historical temperature data indicate that in central Maryland deer self-treatment devices should be operated continuously from the third wk of February until the end of the adult spring activity season. With the prospect of global warming or continuation of the trend of increasingly warmer winters, more days of *I. scapularis* host-seeking activity during January and February are anticipated.

If one uses the presence of any active host-seeking *I. scapularis* as the criterion for operating deer self-treatment devices, then, because the devices are serviced once a week, they should be operated virtually throughout the winter in Maryland. Although this approach hastens achievement of the desired level of control, it is often impractical when time and financial budgets must be met.

The costs of operation are site specific, and the parameters of the cost model must be adjusted accordingly. If deer and ticks are abundant, one pays more for corn and acaricide but many more ticks are killed. Labor costs will also vary. For some treatment areas, sites near the devices are routinely visited for other reasons, so the extra cost for labor and transportation to maintain devices is minimal. However, a contractor who must drive 20 min just to reach the vicinity where the devices are located will cost more.

Because the cost model is simple and the parameters easy to estimate, the cost model can be adapted easily to specific locales. A fundamental decision that must made is where to set the treatment threshold, either in terms of cost/tick or tick attachment rate (determined by which is the more important factor to the user). If using the latter, the cost model can be used to calculate expenses under various attachment rate scenarios. In central Maryland this strategy is particularly useful for the period from the end of December until the third week of February. Because the self-treatment devices target ticks on deer, and it takes female *I. scapularis* $\approx$1 wk to complete feeding, effective ad hoc decisions about when to operate the devices are possible based on current weather conditions. When days occur that have weather favorable for tick activity, the devices should be replenished with corn and acaricide to last 1 wk, and left alone until conditions are met for another treatment. This gives the deer 5 d to use the device and become treated with acaricide, preventing any female tick from completing engorgement. Except for budgeting resources (e.g., corn bait), it is not necessary to be concerned about medium–long range weather forecasts.

Recommendations. Persons intending to use '4-posters' to control *I. scapularis* in Maryland should plan on operating them continuously from October through the first 3 wk of December, and from the third wk of February until the end of the adult spring activity season in late May to early June. In more northerly states, the cut-off and resumption dates for continuous operation will differ by location. During the period from late December to the third wk in February, decisions on whether or not to operate '4-posters' can be based on current weather data and short-term forecasts. When a day having weather favorable for tick activity occurs, one adds corn bait and acaricide to '4-posters.' The replenishment should last 1 wk, unless so many deer regularly use a device that it requires semiweekly replenishment (a situation not unique to winter). After the week has passed, it is again necessary make weather-based decisions.

In conclusion we have demonstrated that by using two models (one for tick activity and another for cost) an efficient approach to operating deer treatment devices in winter can be developed. The tick activity model will vary according to local weather patterns and tick populations, and the cost model will vary by the goals, abundance of ticks and deer, and costs of maintenance. By following this strategy, the cost of operating deer self-treatment devices can be reduced without causing an impact on the success of the treatment program.

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