Efficacy of Amitraz-Impregnated Collars on White-Tailed Deer (Artiodactyla: Cervidae) in Reducing Free-Living Populations of Lone Star Ticks (Acari: Ixodidae)

J. M. POUND,1,2 K. H. LOHMEYER,1 R. B. DAVEY,3 J. A. MILLER,4 AND J. E. GEORGE4

ABSTRACT Over a 7 yr period, we monitored the effect of a commercially available, amitraz impregnated anti-tick collar in controlling free-living populations of lone star ticks, Amblyomma americanum (L.) when manually fitted around necks of white-tailed deer, Odocoileus virginianus (Zimmermann). Study animals in treatment and control groups were confined in 38.8 ha game-fenced and densely vegetated treatment plots in South Texas. Tick densities during years 1 and 7 served as untreated pre- and posttreatment comparisons and treatments occurred during years 2 through 5. Reductions in tick densities in the treatment plot were compared against tick densities in a control plot having similar vegetation and numbers of untreated deer. During years of treatment, indices of control pressure ranged from 18.2 to 82.6 for nymphs and 16.9–78.7 for adults, and efficacy, expressed as percentage control during the final year of treatment, was 77.2 and 85.0%, respectively, for nymphal and adult ticks. These data show that acaricidal collar treatments provide efficacies very similar to those achieved with the existing ivermectin-medicated bait and ‘4-Poster’ topical treatment technologies to control ticks feeding on wild white-tailed deer.

KEY WORDS tick control, neckband, collar, amitraz, white-tailed deer

White-tailed deer (WTD), Odocoileus virginianus (Zimmermann), are keystone hosts for the adult stage of blacklegged ticks, Ixodes scapularis Say, (Barbour and Fish 1993) and lone star ticks, Amblyomma americanum (L.) (Patrick and Hair 1978; Bloemer et al. 1986, 1988). These ticks transmit agents causing Lyme disease, human ehrlichioses, human babesiosis, and other diseases to humans in the eastern United States (Lockhart et al. 1996, Varela et al. 2004). In addition, WTD are marginal hosts for the cattle tick, Rhipicephalus (Boophilus) microplus (Canestrini). Increasing populations of WTD and other wild ungulates along the Texas–Mexico border are compromising eradication efforts meant to prevent the reestablishment of these vectors of bovine babesiosis from the United States (George 1990, Bound et al. 2010). Therefore, in 1991 the U.S. Department of Agriculture–Agricultural Research Service (USDA–ARS) mandated efforts to begin research and development of technologies designed to control ticks feeding on WTD.

As a result, the USDA–ARS has developed and field tested two technologies to aid in controlling ticks feeding on WTD. Studies in South Texas demonstrated that ivermectin-medicated whole kernel corn fed as bait to WTD is quite efficacious in controlling lone star ticks feeding on these animals, as well as reducing populations of free-living ticks within the treatment area (Pound et al. 1996). Larger field trials of this medicated bait technology demonstrated that R. (B.) microplus populations detected on two adjacent ranches located along the Rio Grande River in western Webb County, TX, consisting of 2,630 and 8,903 ha, were both eradicated (Lohmeyer et al. 2011).

The second technology involves a device and method for self-application of a 10% oil formulation of permethrin to deer that was labeled in 2003 by the U.S. Environmental Protection Agency (EPA, EPA Reg. No. 39039-12) to control ticks feeding on WTD, as applied by ARS-patented ‘4-Poster’ Deer Treatment Bait Stations (Pound et al. 1994, 2000a,b; Abel et al. 2011). This device lures WTD to the bait station containing whole kernel corn and as they reach to access the corn the design forces them to rub the side of their heads, necks, and ears against acaricide laden rollers, thus transferring acaricide to the deer. As they groom, acaricide is transferred to their flanks to kill ticks...
located near the rear quarters of the animals. Other than this formulation, marketed as 4-Poster 'Tickicide' by Y-Tex, Corp., Cody, WY, we are aware of no other medications or chemicals currently labeled within the United States for use on WTD for any purpose.

A third, yet to be commercialized method of controlling ticks feeding on WTD is an automatic collaring device for self-application of acaricide laden collars (neckbands) around necks of WTD and other wild ungulates. The initial concept was patented in 1999 (Pound and LeMeilleur 1999), which is in final stages of development by USDA-ARS scientists and cooperators. This fifth generation device is currently being field tested to confirm accuracy and durability of mechanical and electronic components and to demonstrate reliability of unattended collar attachment and detachment functions on unconfined deer. In efforts to simulate acaricidal activity of collars that eventually would be attached automatically, the current study evaluates efficacy of amitraz laden acaricidal collars that are manually applied around necks of WTD against free-living populations of lone star ticks in a large (38.8 ha) game-fenced plot in South Texas.

Materials and Methods

Deer and Study Site. WTD in this study were maintained at the Texas Parks and Wildlife Department–Kerr Wildlife Management Area, Hunt, TX, and all aspects relating to the welfare and treatment of the animals was under the direct supervision and approval of trained professional wildlife management area personnel. The basic experimental design, weekly dry-ice trap tick sampling methods, data collection, and data analyses were similar to those used in studies evaluating the efficacy of systemic treatment of WTD with ivermectin–medicated bait (Pound et al. 1996) and of a topically applied liquid formulation of amitraz applied to WTD by the 4-Poster Deer Treatment Bait Station (Pound et al. 2000a) to control free-living populations of lone star ticks. A single 38.8 ha heavily wooded plot served as the control plot, and a similarly vegetated 38.8 ha plot (Pound et al. 1996) served as the control plot. Plots were rectangular (1,609 × 241 m) and surrounded by 2.4 m high game-proof fences. Vegetation in both pastures was characterized as live oak, Quercus virginiana Miller, savannah with areas of dense mature Ashe juniper, Juniperus ashei Bucholz, and was typical for the Edwards Plateau or Hill Country region of Texas (Hatch et al. 1990). During yearly end to end walking censuses of the elongate rectangular plots by a group of 8–10 participants spaced at similar intervals across the plots, we counted 10–16 and 12–17 deer each year in control and treatment plots, respectively (Table 1).

Acaricidal Treatment. From 1999 through 2003, attempts were made to capture, anesthetize, attach, and maintain potent acaricidal collars around the necks of as many deer as possible within the treatment plot, while deer in the control plot remained untreated. Collars used were commercially available Preventic for Dogs Tick Collars (Virbac, Inc., Ft. Worth, TX) each containing 9.0% amitraz in a flexible polymer matrix. The majority of deer in each plot were mixed-sex adults aged ≥3 yr plus a few yearlings. To prevent injury, the very few young spotted fawns born into the plots were not captured and collared until they completely lost their spots and became 6 mo to 1 yr old. Because of the relatively larger body size of deer, as compared with dogs for which the collars were designed, two collars were applied simultaneously around the necks of adult and yearling deer to maximize treatment. Collars were adjusted around the necks to allow them to easily move from the proximal to distal limits of their necks without sliding off over their heads. After adjustment, excess collaring material was removed to prevent entanglement of the loose ends. From weekly observations of tick densities on a very docile and approachable experimentally collared deer that was held separately in a similarly vegetated and heavily tick infested plot, we estimated duration of collar potency to be between 4 and 5 mo.

Capturing and collar attachment success was low in 2000 and 2001 because of limited success anesthetizing deer captured in common box traps or anesthetizing free-roaming deer by darting (≈0.106 mg succinylcholine chloride per kilogram of body weight, Sosctrin, Bristol–Myers Squibb, Princeton, NJ) with cartridge or pneumatic powered dart guns (Pneu-Dart, Inc., Williamsport, PA). However, during 2002 and

Table 1. Deer densities, collaring success, and percentage indices of control pressure against adult and nymphal lone star ticks from application of amitraz-impregnated collars to white-tailed deer

<table>
<thead>
<tr>
<th>Year</th>
<th>Deer densities per plot</th>
<th>Collaring success</th>
<th>% indices of control pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Deer in control plot</td>
<td>Deer in treatment plot</td>
<td>Individuals collared</td>
</tr>
<tr>
<td>1998</td>
<td>11</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>1999</td>
<td>10</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>2000</td>
<td>14</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>2001</td>
<td>14</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>2002</td>
<td>14</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>2003</td>
<td>15</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>2004</td>
<td>15</td>
<td>16</td>
<td>14</td>
</tr>
</tbody>
</table>

* Years 1998 and 2004 were pre- and posttreatment years during which no collars were applied.

* Both treatment and control plots were 38.8 ha.

* See test for method of calculation.
2003, the success rates increased when deer were trapped using a portable circular rotunda trap, an attached series of working boxes, and a handling chute. Deer were restrained for collaring by coaxing them through the working boxes and into an ARS-patented handling and restraint device or “Lift-chute” (Pound et al. 2003) that was attached to the end of the final working box. As compared with darting and box trapping, the rotunda trapping system facilitated more efficient capturing and recapturing of deer during optimum periods of tick activity. After being examined for ticks, collared, or recollared with fresh potent collars, deer were released back into the treatment plot.

Assessment of Efficacy. During the pretreatment year of 1998 and the posttreatment year of 2004, no deer were treated in either the treatment or the control plots; however, adult and nymphal ticks were sampled weekly to establish comparative pre- and posttreatment baseline tick densities. Adult and nymphal ticks were sampled weekly throughout each year from 1999 through 2003 using the dry-ice trapping method described in Pound et al. (1996). Traps consisted of 1-m² smooth white nylon cloths with small (≈85 g) blocks of dry-ice in the center, and 20 traps each were placed in treatment and control plots. After ∼1 h, ticks on both sides of the cloths were counted and returned to the plot.

To roughly quantify the intensity of treatment pressure that would be placed on free-living ticks during all times of subsequent years, ticks were sampled weekly using the same protocol as above in both treatment and control plots during the pretreatment year of 1998, and data were used to calculate monthly proportions of adult and nymphal ticks questing relative to yearly totals. The weekly counts of ticks sampled for the two plots were added together and the weekly sums were combined by month. The proportions of adult and nymphal ticks that were questing each month were calculated by dividing the total monthly counts in both plots by the total number for the year. These proportions were used as rough indicators of the anticipated proportions of each stage that would be questing monthly and therefore likely to be impacted by acaricidal treatments of deer during subsequent years.

The predicted period of efficacy during which collared deer would be anticipated to have appreciable control effects on questing ticks was determined by rounding the actual collaring dates to the nearest whole month and extending 5 mo forward from this time. The proportion of collared deer exposed to the ticks each month was determined by dividing the number of deer with potent (<4–5 mo old) collars by the total number of deer in the treatment plot. Finally, percentage indices of control pressure were calculated by multiplying the proportion of ticks questing each month by the proportion of collared deer impacting the ticks during the same months then summing the products representing 12 mo per year and multiplying by 100. A t-test with Cochran and Cox approximation of probability level (SAS Institute 2004) was run to determine significance of differences between tick samples from treatment versus control plots for each year. Yearly percentage control values for adults and nymphs were calculated using Abbott’s (1925) formula, and percentage control values comparing between any 2 yr were calculated according to Henderson and Tilton (1955).

Results and Discussion
As mentioned above, from 1999 through 2003 as many deer as possible were captured, collared, and recollared, if necessary, in efforts to maximize efficacy by providing fresh collars during the periods of maximum questing activity of adult and nymphal ticks (Fig. 1). In total, 81.7 and 60.2% of adult and nymphal ticks, respectively, were questing from March through June with peaks of 29.1 and 21.4% occurring during May. In addition, there was a secondary peak of 15.5% for nymphs during September. Adult questing dropped off sharply from 22.3 to 4.8% during June and July and remained ≤2.7% monthly from August through January. Nymphal questing dropped from 15.5 to 1.2% from September through October then
remained \( \leq 1.2\% \) through January. Questing was consistently lowest in November during which no questing adult or nymphal ticks were sampled.

Yearly variation in deer density was beyond our control and varied as a result of natural births and deaths. Considering the challenges of collaring as many different deer as possible, percentages of individual deer collared yearly were relatively high (Table 1). However, percentage indices of control pressure, which take into account both the periods of maximal potency of collars on individual deer and corresponding seasonal variation in proportions of ticks that are questing, indicate that even with 100% of individual deer being collared during 1999 and 2002, the indices of control pressure during these 2 yr varied markedly from 18.2 to 82.6 and from 16.9 to 78.7 for nymphal and adult populations, respectively (Table 1). Unlike the medicated bait and 4-Poster topical treatment technologies that provide essentially all of the deer with continuous and efficacious acaricidal treatment throughout the months of highest tick activity, maximal efficacy of the collaring technology relies heavily on the timing of collar application on deer relative to periods of highest tick activity (Fig. 1). Therefore, the collaring effort had minimal effect in controlling ticks because potent collars were not in place on the majorities of these deer during or 4–5 mo before periods of maximal tick activity. Conversely, during 2002 the rotunda system, the highest indices of control pressure occurred against both nymphal and adult populations in 2002 and 2003 (Table 1) that resulted in substantially increased efficacy during the final 2 yr of treatment (Table 2).

In 1998 through 2003 ticks were sampled weekly on 300 dates with 20 traps each being deployed in treatment and control plots, and an additional 21 wk of trapping were done during from January through May of 2004 for a total of 321 trapping dates in the 7 yr period (Table 2).

![Cumulative number of deer collared from 1999 through 2003.](https://academic.oup.com/jee/article-abstract/105/6/2207/799095/799095)

**Table 2. Efficacy of applications of amitraz-impregnated collars around necks of white-tailed deer in controlling free-living lone star ticks**

<table>
<thead>
<tr>
<th>Year</th>
<th>1999*</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nymphs</td>
<td>Adults</td>
<td>Nymphs</td>
<td>Adults</td>
<td>Nymphs</td>
<td>Adults</td>
<td>Nymphs</td>
</tr>
<tr>
<td>1998 vs year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nymphs</td>
<td>5.4</td>
<td>-54.0</td>
<td>44.3</td>
<td>31.4</td>
<td>38.6</td>
<td>76.2</td>
<td>85.0</td>
</tr>
<tr>
<td>Adults</td>
<td>44.3</td>
<td>31.4</td>
<td>38.6</td>
<td>76.2</td>
<td>85.0</td>
<td>82.6</td>
<td></td>
</tr>
</tbody>
</table>

* No collars were applied during 1998 or 2004; respective percentage control values reflect pre- and posttreatment comparisons of tick densities between treatment and control plots.

b Yearly percentage control values (Abbott 1925) comparing treatment vs control plots; negative values indicate that greater densities of ticks were present in the treatment plot than in the control plot.

c \( P \leq 0.05; \) t-test with Cochran and Cox approximation of probability level (SAS Institute 2004).

d Percentage control values (Henderson and Tilton 1955) comparing 1998 (pretreatment) vs treatment and posttreatment years.
study. This effort involved a total of 12,840 individual tick traps and totals of 26,052 adults and 44,047 nymphs were captured and released which calculates to means of 2.03 adults and 3.43 nymphs per trap over the course of the study. Total adults sampled in the treatment plot decreased from 2,651 in 1998 to 653 in 2003, and conversely those in the control plot increased from 1,721 in 1998 to 4,352 in 2003. Nymphs in the treatment plot decreased from 2,989 in 1998 to 1,624 in 2003, and as with adults, nymphs in the control plot increased from 3,161 in 1998 to 7,127 in 2003.

During 1998, pretreatment comparisons of tick densities between the two plots that were subsequently to be assigned as treatment and control plots showed 5.4 and −54.0% differences in percentage control values for nymphs and adults, respectively (Table 2). The positive value of 5.4% for the nymphal comparison indicates that the density of nymphs in the treatment plot before treatment of deer was numerically quite similar to that of the control plot. However, the negative value for the adult comparison indicates that the density in the treatment plot initially was 54.0% greater than in the control plot. Therefore, a substantial degree of the initial control effort would be expended to reduce the adult density of the treatment plot down to that of the control plot before efficacy of deer treatments would be reflected in positive percentage control values. This situation was demonstrated with the percentage control value for adults between successive years (Abbott 1925; Table 2). For example, percentage control values for nymphs dropped from 44.0 in 1999 to 37.7 in 2000, increased to 64.4 in 2001 and 82.8 in 2002, dropped to 77.2 in 2003, and increased again to 86.6 during the posttreatment year 2004. For adults, the 85.0% value in 2003 is intermediate between and therefore compares very favorably with the second year control values for adults in both the similar ivermectin-mediated bait and 4-Poster trials of 83.4 and 86.4%, respectively (Pound et al. 1996, 2000b).

For nymphs, however, the 82.8 and 77.2% control values during 2002 and 2003, respectively, are somewhat less than second year control values in ivermectin-mediated bait and 4-Poster trials, that is, 92.4 and 87.0, respectively. The lesser efficacies observed with the acaricidal collar treatments are likely the result of control pressure on nymphs that is less than the roughly 100% that would be assumed for the other two technologies. This suggests that as treatment of deer with acaricidal collars becomes logistically and economically feasible, either the efficiency and timing of collar application will need to be more precisely adjusted to the seasonality of tick activity or perhaps the collar design and formulation will need to be improved to greatly extend duration of the period of potency to obviate the mistiming of applications.

In addition to incremental increases in efficacy of treatments from year to year, percentage control values also were calculated that compared pretreatment tick densities in treatment and control plots during 1998 versus densities in treatment and control plots during treatment years from 1999 through 2003 and subsequently versus posttreatment densities in treatment and control plots during 2004 (Henderson and Tilton 1955; Table 2). These calculations demonstrate progressive treatment efficacies of each treatment and posttreatment year taking into consideration the initial densities before treatment. Percentage control values calculated in this manner show efficacy trends for nymphs to be quite similar to the yearly comparisons. However, results for adults calculated in this manner are consistently higher than for the yearly calculations with a positive value in 1999 of 63, then increases to 55.5, 60.2, 84.5, and 90.3 from 2000 through 2003, and a slight decrease to 88.7 during the posttreatment year 2004.

In summary, these data show that acaricidal collar treatments may provide efficacies very similar to those achieved with both the ivermectin-mediated bait and 4-Poster topical treatment technologies, provided that a high enough proportion of deer are effectively treated during periods of high tick activity. However, because the manual capture of WTD strictly for the purpose of applying acaricidal collars would be quite expensive and labor intensive, an unattended automatic self-collaring device was conceptualized and patented by ARS scientists. The principal purpose of the device is to affix acaricidal, visual or radio frequency identification, radio location, global positioning system, anesthesia, and other collars or ‘neckbands’ to WTD and perhaps to similar native or exotic ungulates (Pound and LeMeilleur 1999). Through confidential research and development agreements among ARS scientists and industry partners, a fifth generation computerized and robotically enhanced prototype device has been constructed and is currently being field tested. Collars are currently being passively attached to deer and detached on demand. After final material and design changes are implemented and a final design commercialized, this invention may provide an efficacious, efficient, and economical alternative method for the automatically attaching a wide variety of collars to deer, thus becoming a third commercially viable technology for passively controlling ticks feeding on deer.
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References Cited


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