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EFFICACY OF WHITE-TAILED DEER (*ODOCOILEUS VIRGINIANUS*) TREATMENT FOR CATTLE FEVER TICKS IN SOUTHERN TEXAS

Chase R. Currie,[1,5] David G. Hewitt,[1] J. Alfonso Ortega-S.,[1] Greta L. Schuster,[2] Tyler A. Campbell,[3] Kim H. Lohmeyer,[4] David B. Wester,[1] and Adalberto Pérez de León[4]

[1] Caesar Kleberg Wildlife Research Institute, Texas A&M University–Kingsville, 700 University Boulevard, MSC 218, Kingsville, Texas 78363, USA
[2] Department of Agriculture, Agribusiness, and Environmental Science, Texas A&M University–Kingsville, 700 University Boulevard, MSC 218, Kingsville, Texas 78363, USA
[3] East Wildlife Foundation, San Antonio, Texas 78216, USA
[4] USDA-ARS Knipling-Bushland US Livestock Insects Research Laboratory, Kerrville, Texas 78028, USA
[5] Corresponding author (email: chase@sanpedroranch.com)

ABSTRACT: White-tailed deer (*Odocoileus virginianus*) serve as a host for cattle fever ticks (*Rhipicephalus* [*Boophilus*] *microplus* and *R.* [*B.*] *annulatus*; CFTs); therefore, deer are a concern for CFT control programs in southern Texas. Systemic (oral delivery of ivermectin) and topical (permethrin on pelage) treatment devices have been developed for white-tailed deer; however, the efficacy of these treatment options has not been determined for CFTs in southern Texas. Our objectives were to evaluate the effectiveness of CFT treatment strategies by 1) measuring exposure rates of deer to the acaricides permethrin and ivermectin, 2) determining the relationship between CFTs on deer and exposure to the acaricides, and 3) determining if photos from remote cameras at medicated bait sites can be used as a measure of acaricide treatment. We captured 327 deer at four sites in southern Texas. Deer visitation to medicated bait sites was monitored using remote cameras from March 2010 to February 2012. There was no relationship between the presence of permethrin and the probability of being infested with CFTs ($P \geq 0.336$). The probability of infestation with CFTs decreased as serum ivermectin levels increased for male ($n=18$, $P=0.098$) and female ($n=33$, $P<0.001$) deer. Our results indicate ivermectin may be more effective in treating CFTs than permethrin; thus it would be worthwhile to develop topical acaricides other than permethrin for treating white-tailed deer in southern Texas.

Key words: Bait sites, cattle fever ticks, ivermectin, permethrin, white-tailed deer.

INTRODUCTION

Understanding the ecology of wildlife is integral of control and management of diseases that affect livestock and humans. Overpopulation is one factor that can exacerbate wildlife's involvement in the emergence and reemergence of infectious diseases (Paddock and Yabsley 2007). In the case of white-tailed deer (*Odocoileus virginianus*), they also serve as hosts of parasitic arthropods, especially ticks, that serve as pathogen vectors (Campbell and Vercauteren 2011). Thus, deer can be involved in disease cycles as a reservoir for infectious agents, or indirectly as a reservoir host of tick vectors transmitting infectious agents that are pathogenic to other animals and humans (Miller et al. 2013).

Babesia bovis and *B. bigemina* are apicomplexan tick-borne protozoa causing bovine babesiosis, also known as cattle fever. Cattle fever ticks (CFTs), including *Rhipicephalus* (*Boophilus*) *microplus* and *R.* (*B.*) *annulatus*, are one-host ticks with a life cycle that includes an on-host and an off-host phase (Pérez de León et al. 2012). Cattle are the primary hosts of CFTs; however, various life stages of ticks have been found on white-tailed deer, indicating CFTs are also capable of completing their life cycle on deer (Kistner and Hayes 1970). White-tailed deer are neither a transient host nor reservoir of *B. bovis* and, therefore, are likely not affected by babesiosis (Ueti et al. 2015). However, deer support the dispersal and maintenance of the CFT vectors (Pérez de León et al. 2014). Beginning in 1906 the US Department of Agriculture, Cattle Fever Tick Eradication Program (CFTEP) worked to eradicate CFTs from the US. The US was declared CFT-free in 1943, a goal that was facilitated by low deer population densities across most of the US (Pound et al. 2010). In 1938 a permanent quarantine zone (PQZ) was established in south Texas to contain incursions of CFTs from Mexico where they are endemic. White-tailed deer are now more abundant than in the early and mid-1900s. In some areas their populations have doubled, complicating efforts by the CFTEP to keep the US CFT-free (Pérez de León et al. 2012).

White-tailed deer serving as alternative hosts for CFTs present a major challenge to eradication. Wildlife are more difficult to treat than cattle, in that wildlife move freely across the landscape and are not easily captured. Furthermore, disease and parasite eradication programs require treatment of a large portion of the target population with appropriate intervention (Bowman 2006). Therefore, the success of pest eradication efforts is based on how effectively treatment techniques deliver an adequate dose of pesticide, medication, or vaccine to the target population. Techniques for treating free-ranging large mammals carrying tick-borne pathogens have been developed (Liegner 1991; Duncan and Monks 1992; Sonenshine et al. 1996; Pound et al. 2000). White-tailed deer have been treated extensively in the northeastern US using the 4-Poster to control Ixodid ticks to reduce the risk of tick-borne disease (Pound et al. 2009). In their 5-yr study in five northeastern states, Pound et al. (2009) found that 76% of deer (range: 12–89%) in the study areas accessed the 4-Poster, which was a sufficient proportion of the population to reduce tick loads on deer. Thus, the 4-Poster treatment station was a successful tool in delivering acaricide to ticks infesting deer.

A systematic quarantine zone for cattle fever ticks still exists along the Texas-Mexico border (Racelis et al. 2012), and properties in south Texas continue to be quarantined because of the presence of CFTs. White-tailed deer appear to contribute to the persistence of tick populations in this area (Busch et al. 2014). From 2006 to 2008, the number of premises under quarantine increased from 46 to 85. Furthermore, outbreaks in the free zone, beyond the PQZ, reached an all-time high of 146 premises in 2009 (Pérez de León et al. 2010). Deer are treated using ivermectin-laced corn from February to July and the 4 Poster permethrin delivery system from August to January. Permethrin is used to topically treat deer because ivermectin cannot be fed during hunting season when deer meat may be consumed by humans.

The ability to treat wild populations of deer for CFTs is important to the success of the CFTEP and for the protection of the US livestock industry. Monitoring deer exposure to acaricides is required to assess the effectiveness of programs to control ticks on deer. Therefore, our objective was to evaluate the effectiveness of CFT treatment strategies by 1) measuring exposure rates of deer to the acaricides permethrin and ivermectin, 2) determining the relationship between CFTs on deer and exposure to the acaricides, and 3) determining if photos from remote cameras at medicated bait sites (bait sites hereafter) can be used as a measure of acaricide treatment. We tested the hypothesis that the probability of deer having CFTs is a function of ivermectin serum levels and the presence of permethrin on the deer's head, ears, or neck. Furthermore, we predicted a positive relationship between the number of photographs of a deer at bait sites and that deer's 1) serum ivermectin concentrations and 2) the probability of presence of topical permethrin.

MATERIALS AND METHODS

We monitored deer on privately owned ranches along the Rio Grande River in southwestern Zapata County, Texas, USA, near Falcon Reservoir. The climate is semiarid and characterized by long, hot summers and short, cool winters. Mean monthly temperatures range from an average low of 13 C in January to a high of 31 C in July. The average annual temperature is 23 C, and mean annual precipitation is 38 cm (Norwine et al. 2007). The Palmer Drought Severity Index averaged across months for this region of Texas was 1.78 (moderate rainfall) and –3.47 (severe drought) for 2010 and 2011, respectively (National Oceanographic and Atmospheric Administration, Satellite and Information Service 2019). Associated woody vegetation includes honey

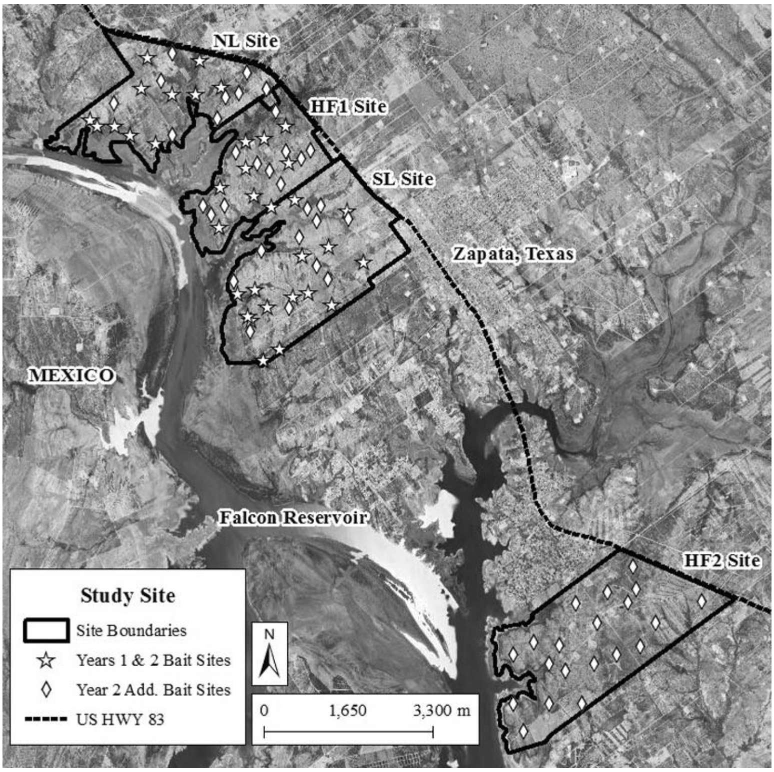

FIGURE 1. Study site design and bait site layout in Zapata County, Texas, USA, March 2010–April 2012.

mesquite (*Prosopis glandulosa*), huisache (*Acacia farnesiana*), spiny hackberry (*Celtis pallida*), cenizo (*Leucophyllum frutescens*), creosotebush (*Larrea tridentata*), blackbrush (*Acacia rigidula*), guajillo (*Acacia berlandieri*), and guayacan (*Porliera angustifolia*).

From March 2010 to February 2012, we monitored bait-site visitation on two sites surrounded by a 1 m tall livestock fence (low-fenced sites: SL, 812 ha; 26°53′33″N, 99°17′24″W, and NL, 561 ha; 26°56′17″N, 99°20′20″W), and one site surrounded by a 2.4 m fence designed to limit deer movement on the northern, eastern, and southern boundaries (high-fence site; HF1, 450 ha; 28°55′35″N, 99°18′19″W). Falcon Reservoir bordered the southern boundary of NL and the western boundary of SL and HF1 (Fig. 1). From March 2011 to February 2012 (year 2), we monitored bait-site visitation on an additional high-fenced site (HF2, 878 ha; 26°50′25″N, 99°14′55″W) surrounded by a 2.4 m fence on the northern and southern boundaries. The western boundary of HF2 was Falcon Reservoir, and the eastern boundary, Highway 83. The eastern and western boundaries of HF2 were not fenced. Additionally, US Highway 83 served as the eastern boundary for all study sites (Fig. 1). Deer within a study site could move among bait sites; however, movement barriers as described above restricted deer from moving among study sites. Properties were under a federal quarantine because of the presence of CFTs and bait sites had been in operation for 3 yr.

Deer evaluated in the study were captured using a net gun fired from a helicopter (Webb et al. 2008). The helicopter pilot selected the deer without reference to sex or age, except for a capture during November 2010, which consisted of all males that were targeted for a movement study to assess habitat use relative to tick densities. Once captured, deer were blindfolded and manually restrained. Deer age was determined by the tooth replacement and wear technique (Severinghaus 1949), and each deer received two cattle ear tags, one in each ear, of unique color and number combinations. Ear tags were used to individually identify deer at bait sites. To assess the presence of permethrin on the pelage, captured deer were rubbed with one 12.5 cm disk Whatman® No. 1 filter paper disc (Whatman International Ltd., Maidstone, UK) on the head, ear, neck, and flank region (Lohmeyer et al. 2013). The filter paper disc was stored between aluminum foil sheets for processing. Whole blood was drawn via jugular venipuncture and stored on ice for transportation to the laboratory where it was processed. Whole blood was drawn during the February, March, and April 2011 captures as well as the March and April 2012 captures to assess ivermectin concentrations in the serum. Captured deer were examined thoroughly for CFTs by trained US Department of Agriculture-Animal and Plant Health Inspection Service CFTEP personnel. For purposes of this study, if one CFT was found on a deer, it was considered infested. Capture and handling procedures were approved by the Texas A&M University–Kingsville Institutional Animal Care and Use Committee (Approval no. 2009-09-21B).

Permethrin analyses were as described by Lohmeyer et al. (2013). Briefly, filter paper discs were soaked in high-performance liquid chromatography (HPLC)-grade acetonitrile overnight and the filtered extract analyzed against permethrin standards using HPLC. Serum ivermectin concentration was analyzed using the method for bovine serum described by Oehler and Miller (1989).

Both the systemic (ivermectin-medicated corn) and topical (4 Poster) treatment techniques were used to treat deer for CFTs. The systemic technique consisted of ivermectin-medicated corn (Pound et al. 1996) fed ad libitum, whereas the topical technique used two paint rollers impregnated with acaricide containing 10% permethrin attached to each feeder tube (Pound et al. 2009). Whole-kernel corn was fed ad libitum and used as an attractant for deer to the 4 Poster treatment device. Ivermectin-medicated corn must be withdrawn from the feeders 60 days prior to and during the hunting season; therefore, the topical treatment device was used August 1–January 31, and the systemic treatment was used 1 February–31 July. Feed was distributed via elevated, four-snout feeders (Thunder Valley Whitetails, Montoursville, Pennsylvania, USA). The bait sites were surrounded by a 0.75-m-high panel fence to deter nontarget animals including feral swine (*Sus scrofa*) and collared peccaries (*Pecari tajacu*). Bait site density was 0.019/ha in 2010 and 0.033/ha in 2011.

We used motion-triggered cameras (Cuddeback Capture, Park Falls, Wisconsin, USA) to monitor deer visitation rates at bait sites from March 2010 to February 2012. We monitored 35 bait sites on the SL, HF1, and NL from March 2010 to January 2011 (Year 1). In Year 2, 86 bait sites were monitored on the SL, HF1, NL, and HF2 from March 2011 to February 2012. The approximate median distance between feeders was 894 m and 678 m in years 1 and 2, respectively. Bait sites were monitored for six 24 hr periods each month in 2010 and seven 24 hr periods each month in 2011. Twenty-five cameras were rotated among study sites such that each study site was monitored for 1 wk/mo. Cameras were placed on a metal t-post 5 m from bait sites in a north or south orientation 1 m above the ground. Feeders numbered so that bait sites could be uniquely monitored. Cameras were set with a 1 min delay between photos. A 1 min delay was used as a compromise between obtaining multiple photos of individual deer during a single feeding bout because of a short delay versus failing to obtain a photo of some deer because of a long delay. We recorded the number of times each marked deer was photographed at bait sites during each sampling period. To assess the relationship between acaricide levels and bait site visitation, we examined intensity of bait site use for individually marked deer that visited at least one of the bait sites on each of the study sites, during a given sampling period.

We used a chi-square test of independence to determine the relationship between the presence of permethrin and the frequency of deer being infested with CFTs; age classes of deer were combined within sex. We used logistic regression to model the relationship between the probability of CFT infestation and serum ivermectin concentration. Separate analyses were completed for adult males and females. For adult males, animal-to-animal variability was modeled by including animal ID as a random effect. Repeated observations were collected from several females; possible overdispersion was modeled with the GLIMMIX procedure (SAS Institute Inc., Cary, North Carolina, USA). The GLIMMIX procedure fits statistical models that have a response that may not be normally distributed. Additionally, we assessed the relationship between the number of photos of each adult deer and ivermectin concentration and the presence of permethrin using Pearson's correlation analysis.

RESULTS

We captured 327 deer (189 females, 138 males) from March 2010 to April 2012, of which 70 were recaptures. Seventy-four deer were captured in SL, 55 in NL, 132 in HF1, and 66 in HF2. We collected permethin and ivermectin data from 115 and 152 deer, respectively. The CFT infestation rate of deer captured during year 1 (81.1%; n=133/164) was three times higher than that of deer captured during year 2 (27.0%; n=44/163). However, ivermectin levels were 100% higher in the serum of deer captured in year 1 than in

TABLE 1. The percentage of captured white-tailed deer (*Odocoileus virginianus*) with permethrin present on their pelage or ivermectin detected in blood serum along with ivermectin concentrations (parts per billion [ppb]) and standard errors in Zapata County, Texas, USA.

Year[a]	Permethrin (%)		Ivermectin (%)		Ivermectin concentration (ppb)	
	Males	Females	Males	Females	Males	Females
1	71	11	100	64	32 (SE=8.57)	21 (SE=3.83)
2	89	63	88	59	72 (SE=6.65)	32 (SE=4.40)

SE = standard error.
[a] Year 1 = March 2010–February 2011; Year 2 = March 2011–February 2012.

deer captured in year 2 (52 vs. 26 ppb). When comparing males and females between years, 100% and 88% of males had detectable ivermectin levels in their serum in years 1 and 2, respectively, whereas, 64% and 59% of females had detectable ivermectin in their serum in years 1 and 2, respectively. Furthermore, a greater proportion of males had permethrin on their skin in year 1 (71% vs 11%) and year 2 (89% vs 63%), when compared to females (Table 1).

There was no statistical relationship between the presence of permethrin and the frequency of a deer being infested with CFTs (χ^2 (1, n=76) = 1.259, $P \geq 0.336$; Table 2). For all males (n=18, P=0.098) and females (n=33, $P<0.001$), the frequency of deer with CFTs decreased as serum ivermectin levels increased (Fig. 2). Calculating infestation rates for deer with 0 ppb of ivermectin in serum indicated 67% of untreated males and 53% of untreated females were infested with CFTs. Additionally, ≤10% of males and females with serum ivermectin ≥69 ppb and 34 ppb, respectively, were infested with CFTs. We assessed serum ivermectin of 24 fawns; no fawns were assessed for permethrin. Only 33% (8/24) of captured fawns had detectable serum ivermectin, and only 25% had >20 ppb. Furthermore, 48% of captured fawns were infested with CFTs.

We monitored deer for 9,270 camera nights yielding >90,000 photos. The presence of permethrin and concentrations of serum ivermectin of individual deer were correlated with the number of photos for each deer (r=0.612, $P<0.001$ n=234; r=0.668, $P<0.001$, n=311, respectively). For males, the presence of permethrin (r=0.688, $P<0.001$, n=160) was

TABLE 2. Percentage of white-tailed deer (*Odocoileus virginianus*) infested with cattle fever ticks based on the presence of permethrin (PR) on their pelage in Zapata County, Texas, USA.

Capture date	Exposed to PR[a]		Not exposed to PR[b]		
	n	% infested	n	% infested	P value
29 September 2010	12	60	48	76	0.252
29 November 2010	26	93	1	100	NA
28 September 2011	19	36	9	67	0.336

NA = not applicable.
[a] χ^2=1.313, $P \geq 0.252$.
[b] χ=1.259, $P \geq 0.336$.

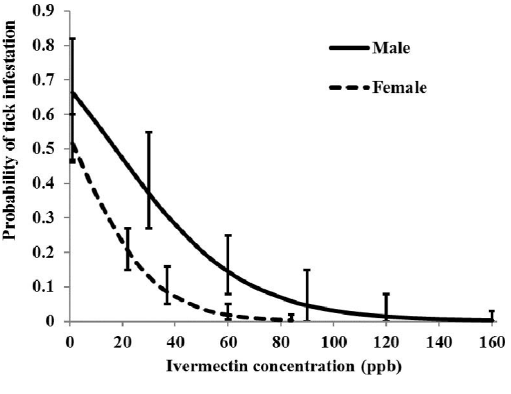

FIGURE 2. Relationship between probability of captured, adult male (n=18) and female (n=33) white-tailed deer (*Odocoileus virginianus*) being infested with cattle fever ticks as a function of serum ivermectin concentrations (ppb) from March 2010 to April 2012 in Zapata County, Texas, USA. Vertical bars are 95% confidence intervals.

more strongly correlated than ivermectin concentration (r=0.412, P=0.089, n=188) with number of photos. For female deer, there was a moderately strong correlation between the number of photos and either the presence of permethrin (r=0.747, P=0.002, n=74) or serum ivermectin concentration (r=0.688, $P<0.001$, n=123).

DISCUSSION

We assessed the utility of bait stations in controlling CFTs on deer in southern Texas. This is part of an integrated approach to eradicate CFTs in the PQZ and thereby minimize risk of cattle fever invasion (Pérez de León et al. 2012). Our study sites were unique in that deer movement was limited by barriers, such as fencing. Therefore, our results should be interpreted under these circumstances. The CFTEP uses both systemic and topical acaricides to treat deer for CFTs. Our results indicate that the ivermectin systemic treatment may be more effective in decreasing CFTs on deer when compared to permethrin based topical treatments. Our results and data from previous research indicate that ivermectin can reduce CFTs on deer (Pound et al. 2010). However, we were unable to ascertain a relationship between permethrin detection on deer and the probability of deer being infested with CFTs. Perhaps permethrin was not as effective in controlling CFTs due to possible tick resistance to permethrin in our study area (Busch et al. 2014). The viability of ticks infesting deer exposed to acaricides was not assessed, nor were collected ticks assessed for permethrin resistance.

A decrease in the number of captured deer infested with CFTs was observed during the second year of the study. However, the presence of permethrin in deer did not change throughout the study. Higher concentrations of ivermectin in year 1, compared to year 2, suggest that the drier environmental conditions during the second year may have caused a decline in tick reproduction and survival, which may have contributed to the decline in the proportion of captured deer infested with CFTs. The variable environment in southern Texas may affect CFT population dynamics. The number of eggs laid/*R. annulatus* female was greatest at 25–35 C and decreased at temperatures outside this range when relative humidity was held constant (92.5%; Davey 1988). At temperatures >40 C, female ticks are less efficient at converting body nutrients into egg production and thus produce fewer eggs. Females died when held at 45 C for an extended period (Davey 1988). *Rhipicephalus microplus* is responsible for most of the cattle fever in Zapata County (Lohmeyer et al. 2011). The potential for range expansion of climate suitable for survival of CFTs in the southern US could increase by midcentury, which increases the risk for reinvasion by these ticks and cattle fever into major cattle-producing areas (Giles et al. 2014). Deer densities in Zapata County, which can reach 30 deer/km^2, highlight the need for science-based approaches to manage deer populations, from a density standpoint, that also benefit the CFTEP (Birdsall and Hewitt 2014; Birdsall 2015).

Once marked animals are in the population, it is possible to use motion-triggered cameras to estimate the proportion of deer treated at medicated bait sites. Motion-triggered cameras can be effective in photographing a large proportion of marked animals at bait sites. In Mississippi, 92% and 89% of marked male and female white-tailed deer, respectively, were recaptured on camera (McKinley et al. 2006). Additionally, Jacobson et al. (1997) photographed 100% and 88% of individually marked deer over a 2 yr period in Texas. In our study, there was a moderately strong correlation between acaricide levels of captured deer and the number of photos at bait sites for the same deer, indicating that motion-triggered cameras were a good measure of deer visitation to bait sites and subsequent exposure to medications.

Due to the high density of bait sites on our study sites, both males and females were visiting more than one bait site per night with males visiting 1.12 bait sites per night and females, 1.03 bait sites per night (Currie

2013). The higher proportion of males with detectable acaricide is consistent with the camera data suggesting males had greater access to bait sites. Results from studies where cameras were used to assess deer visitation patterns to medicated feed sites showed that a greater proportion of males visited bait sites (Currie 2013). Adult male white-tailed deer are typically dominant over other sex and age classes throughout the year (Hirth 1977; Donohue et al. 2013), and, if dominant animals are feeding, subordinates may be reluctant to approach a concentrated food source (Ozoga and Verme 1982). Based on data from motion-triggered cameras on our study site, male visitation at bait sites was 113% greater than female visitation (Currie 2013). Moreover, male deer on our study site fitted with GPS collars as part of another study had a greater proportion of locations ≤50 m from a bait site than did females (0.045 vs. 0.002; Currie, 2013). High male visitation rates may have prevented female deer from receiving acaricides at bait stations.

The low proportion of fawns with ivermectin in their serum and photographic data collected at bait sites indicated <33% of fawns visited bait sites (Currie 2013). Dominance hierarchies may have caused fawns to avoid bait sites, or fawns may have been excluded from bait sites by fencing. Adult and yearling bucks and does are dominant over fawns at feed sites in southern Texas (Donohue et al. 2013). Additionally, fences around feed sites to deter nontarget species inhibited fawns from accessing supplemental feed (VanBogelen 2010). Fence heights around bait sites in our study were similar to those evaluated by VanBogelen (2010).

Provisioning of wildlife during the hunting season is often prohibited; therefore, alternative treatment methods need to be evaluated to help mitigate pest/disease spread by wildlife during this season. White-tailed deer pose a significant threat to the CFTEP and other pest/disease eradication programs. As deer populations increase in most areas of the US, it will be important for pest and disease managers to design and implement effective treatment techniques. Research on deer social behavior is helping disease managers increase the effectiveness of eradication efforts when using concentrated food sources to deliver medication. Our results indicate ivermectin may have been more effective in treating CFTs than permethrin. This warrants investigations on the use of topical acaricides other than permethrin for use during the hunting season. In addition to continued evaluation of alternative acaricides, future efforts of the CFTEP could focus on development of techniques to treat female deer and fawns thereby increasing the proportion of treated deer. Furthermore, more research is needed to determine whether deer infestation rates relate to cattle fever risk in cattle.

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