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ORIGINAL ARTICLE

Sustained Control of Gibson Island, Maryland, Populations of *Ixodes scapularis* and *Amblyomma americanum* (Acari: Ixodidae) by Community-Administered 4-Poster Deer Self-Treatment Bait Stations

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Abstract

In 1998, twenty-five 4-Poster deer treatment bait stations were deployed on Gibson Island (GI), Maryland, as part of the U.S. Department of Agriculture (USDA) Northeast Area-Wide Tick Control Project. Treatments concluded in June 2002, having achieved 80% and 99.5% control of blacklegged ticks, *Ixodes scapularis*, and lone star ticks, *Amblyomma americanum*, respectively. No area-wide tick control was attempted again on the island until 2003, when 15 Dandux™-manufactured 4-Posters were purchased by the GI Corporation and operated until the present. Annual flagging at sites on the island and a similar untreated area on the nearby mainland in May and June from 1998 to 2007 has demonstrated that populations of host-seeking nymphs of both tick species have remained at consistently low levels on the island during GI Corporation administration of the 4-Posters, in spite of 40% fewer 4-Posters and increased deer density during 2003–2007.

Key Words: Amitraz—Corn bait—Permethrin—Tick control—White-tailed deer.

Introduction

MARYLAND (MD) HAS BEEN AMONG THE 10 states with the highest number of reported cases of human Lyme disease since the 1990s (CDC 2007). *Ixodes scapularis* Say is well established on the Delmarva Peninsula and throughout central and southern MD. However, few cases of Lyme diseases have been reported from the westernmost counties (Maryland Department of Health and Mental Hygiene 2007). Gibson Island (GI), in Anne Arundel County, is connected to the western shore of the Chesapeake Bay by a gated causeway. From 1998 to 2006 this county has reported the highest (four times), second highest (once), third highest (twice), and fourth highest (twice) number of cases of Lyme disease per year in MD (MD Department of Health and Mental Hygiene 2007). Armstrong et al. (2001) reported that 17.4% of the *I. scapularis* nymphs collected by flagging on GI (1994–1996) were infected with the pathogen causing Lyme disease.

Although Lyme disease cases have been reported from GI, based on serological evidence, ticks submitted by residents, and interviews of residents, Armstrong et al. (2001) surmised that lone star ticks, *Amblyomma americanum* (L.), were the major tick problem on the island. Lone star ticks are commonly found on the Delmarva Peninsula and counties bordering the Chesapeake Bay (Carroll 2007). Besides being a nuisance because they readily bite humans, *A. americanum* are known to transmit ehrlichial pathogens that are harmful or even fatal to humans (Childs and Paddock 2003), with MD among the top five states reporting the most cases of human monocytic ehrlichiosis (CDC 2005).

In fenced portions of the NASA Goddard Space Flight Center (Greenbelt, MD) campus, Solberg et al. (2003) used 4-Posters treated with 10% permethrin to reduce tick populations. The USDA Northeast Area-Wide Tick Control Project (NEATCP) evaluated the efficacy of the 4-Poster technology in reducing populations of *I. scapularis* and *A. americanum* over a 5-year period (Fish and Childs 2009, Pound et al. 2009). In 1998, GI was added as a secondary NEATCP study site in MD. After an ~1-year hiatus following the cessation of NEATCP treatments on the island in 2002, the GI Corporation

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purchased newly marketed 4-Posters and resumed treatments. Populations of *I. scapularis* and *A. americanum* on GI and at an untreated comparison area on the nearby mainland were sampled annually from 1998 to 2007. We report the results of the 4-Poster interventions on GI during this 9-year period.

Materials and Methods

Study site

GI is in the Chesapeake Bay ~0.2 km from MD's western shore to which it is connected by a gated causeway. The island is inhabited throughout the year with residential areas situated primarily on the periphery. Excluding coastal marshes, the ~3.1 km^2 island is ~70% forested and includes a golf course. The population of white-tailed deer on GI was estimated to be 60–70 animals during the NEATCP years, but based on corn consumption from 4-Posters, hunter kills, and counts by GI personnel the number of deer was estimated to be 2–2.5 times greater by 2007. Residents of GI report seeing deer swimming to the island from the mainland, but the frequency of these events is unknown. In 1998, a comparison site of similar size, habitat, land usage, and deer and tick densities was selected, comprising John Downs Memorial Park and some adjoining private lands (Anne Arundel County, MD). No current estimate of deer density is available for the comparison area. Construction of a water drainage basin in a nonpark portion of the comparison area in 2005 destroyed part of one sample site. The comparison site was 3.2 km from the nearest part of GI.

Treatments

In the late spring of 1998, twenty-five 4-Posters were deployed on the island at locations where deer activity was observed or there were signs of regular deer presence (Carroll et al. 2003). Corn bait and acaricide (2% amitraz, Point Guard™; Hoechst-Roussel, Somerville, NJ) were replenished weekly March through mid-December. Because a substantial *A. americanum* population existed on the island and numerous larvae, nymphs, and adults of this species also feed on deer, treatments were extended through the summer to accelerate control. Amitraz was applied weekly according to the rates prescribed by NEATCP experimental protocols. When NEATCP treatments ended in June 2002, 4-Posters were not yet commercially available. During NEATCP, the corn bait was purchased by the GI Corporation and their personnel replenished it in the 4-Posters as directed by NEATCP personnel who applied the amitraz, cleaned, repaired, and relocated the devices and assisted in replenishing the corn bait.

In 2003, the GI Corporation purchased 15 Dandux™ (Ellicott City, MD)–manufactured 4-Posters and began operating them on the island. Thirteen 4-Posters were still in operation in 2007. Some Dandux 4-Posters were placed at or near old NEATCP locations or at new sites on the island to coincide with patterns of deer activity. The Dandux 4-Posters were constructed of rotationally molded polyethylene plastic; those used during the NEATCP were made of galvanized sheet metal except for the post assemblies. The paint rollers used with the Dandux 4-Posters were fibrous (Pylam™ Extra Rough Surface, 3.17 cm nap; Linzer, Wynandanch, NY) rather than of the foam type used in the NEATCP. Instead of amitraz (approved by the Environmental Protection Agency for use on deer only for the NEATCP), 4-Poster Tickicide® (10% permethrin; Y-Tex, Cody, WY) was applied to the rollers of the Dandux 4-Posters.

The weekly application of acaricide to 4-Posters followed the manufacturer's Environmental Protection Agency–approved label. Based on the weight of corn consumed the previous week, each roller received 2.5 mL acaricide for 2.3–9.2 kg corn consumed, increasing by 2.5 mL/roller for each additional 4.5 kg increment of corn consumed up to 70.5 kg. For every additional 11.4 kg corn consumed above 70.5 kg, an additional 5 mL of acaricide/roller was applied.

Sampling tick populations

Host-seeking nymphs of both tick species were sampled annually on three dates from late May to the end of June with two exceptions. There were only two sample dates in 2005, and the third sample date in 2007 was July 3. Fifteen sites each on GI and at the comparison (control) area were sampled on the same day (8:00–12:30 EDT) by two groups of tick flaggers so that some treated and untreated sites were sampled simultaneously each date. Ticks were sampled by flagging as described by Carroll et al. (2003). Captured ticks were returned to the sample routes, except on the final sampling date each year during the NEATCP, when ~50 *I. scapularis* nymphs were collected to be assayed for *Borrelia burgdorferi.* In MD, adult *A. americanum* also seek hosts in May and June, so we also recorded the numbers of adults captured. Adult *I. scapularis* and larvae of both species were sampled once a year during NEATCP, but this sampling was discontinued at the end of the project.

Statistical analysis

To satisfy the ANOVA assumption of homogeneous variances for Poisson distributed data, the counts of ticks (from 1998 to 2007) were square-root transformed before analysis. Adults and nymphs of *A. americanum* were modeled separately from one another and *I. scapularis* nymphs. Julian day effects and weather variables were predictive of *I. scapularis* and *A. americanum* sample counts in this area in 1998–2002 (Carroll et al. 2009), so these were included in our models as appropriate. A Julian day effect models the trend in counts as they change over the sampling season, typically as a linear or quadratic trend with the Julian day as an independent variable. Daily counts are known to respond to local weather conditions, such as temperature, humidity, wind, etc., and may be influenced by the prior day's weather when sampled in the morning (Carroll and Kramer 2003). Including relevant weather variables as covariates helps reduce the day-to-day count variation influenced by the weather.

We considered site (within location) a random factor. Because sites were visited several times during the sampling period, we allowed for covariances due to this repeated measures aspect. A time series model was used where the magnitude of the covariance depended on how many days separated the samples.

All models included both a treatment effect and a treatment by year interaction effect, because the treatment effect varied (increased) over time. We used linear contrasts within the model to test if tick populations remained lower in the treated areas. These contrasts test if the difference between the pretreatment densities at the control and treatment sites (1998 or 1999, depending on tick cohort) changed significantly during each following year. So, for example, if there was no difference between tick populations at control and treatment areas in 1998, and no difference between them in 2006, the contrast would not be significant, even if both control and treatment tick levels had decreased markedly by 2006. The expectation is that tick densities at the control area fluctuate around some long-term mean, while those at the treatment area, which initially were near those at the control tick area, decrease and subsequently remain low. In this case, the contrasts should show that there were significant changes in tick densities at the treatment area.

We also tested the effect at GI due to change in operation of the 4-Posters using contrasts, contrasting the (adjusted) number of nymphs in 2002–2004 (nymph populations affected by NEATCP operations) with the (adjusted) number of nymphs in 2005–2007 (nymph populations affected by GI Corporation operations), for both species. The adjustments were for site, weather, and Julian day effects, and these contrasts were made in the context of the nymph model used for each species (i.e., parameter estimates for the covariates were the same as those used for other contrasts).

Results

Annual counts of host-seeking nymphs for the period of 2003–2007 showed that the densities of *I. scapularis* and *A. americanum* at GI remained at quite low levels after the end of the NEATCP treatments (1998–2002) (Fig. 1). All contrasts for both adults (*A. americanum*) and nymphs were significant ($p < 0.05$) for all years except for *A. americanum* nymphs in 2007, when counts at the Downs Park untreated comparison area were the lowest since 1998; that is, both treated and untreated sites had similarly low tick densities. This contrast included 1999 (before a treatment effect on densities of host-seeking nymphs would be expected to be observed), during which tick densities were also similar for both sites, though much higher. After 2002, the mean total *I. scapularis* nymphs captured per sample date for GI did not exceed 22.1% or 18.8% of the per sample date means for 1998 and 1999 respectively, a period before an effect of the treatments on host-seeking nymphs would have been observed (Fig. 1, panel 3). In 2006 and 2007, averages of 13.7 ± 1.33 and 12.0 ± 4.04, respectively, total *I. scapularis* nymphs were captured per sample date, that is, 12.1% and 10.6% of 1998 numbers and an average of <1 nymph captured per sample site. Unlike *A. americanum* densities, *I. scapularis* densities at the Downs Park comparison area slipped lower during post NEATCP, and fell to their lowest level in 2007. Nevertheless, all treatment contrasts involving pre- and posttreatment years for *I. scapularis* were significant ($p < 0.05$).

Mean numbers for the total *A. americanum* nymphs captured during each of the three sample dates each year are depicted in Figure 1, panel 2. Since 2002, the mean total nymphs captured per sample date for GI have not exceeded 19.1% or 16.3% of the per sample date means for 1998 and 1999, respectively. The lowest densities of nymphal *A. americanum* on GI were in 2002 and 2003, but even in 2006 the average total number of nymphs captured per sampling date for the 15 sites was <10. In contrast, the numbers of *A. americanum* captured at the Downs Park comparison area were relatively high from 2003 to 2005, ranging from 199 to 254 total nymphs per sample date. Collections of adult *A. americanum* on GI also remained low, with only one male and one female captured during 2007. In 2007, persistent unusually dry weather may have contributed to low counts for both species.

Predictive weather variables differed among the three models. For adult *A. americanum* and nymphal *I. scapularis*, we found that the average (positive coefficient), minimum (negative coefficient), and maximum (negative coefficient) temperatures for the previous day were useful predictors of tick counts. For nymphal *A. americanum*, we found only the average temperature (positive coefficient) for the previous day useful. Julian day effects were predictive of counts for all models, but a Julian day by year interaction with year was significant only for *I. scapularis* nymphs. For this model the Julian day effect differed among years, largely due to 2005, with a steeper linear regression slope. A Julian day quadratic effect was also in this model for these data, with a negative coefficient.

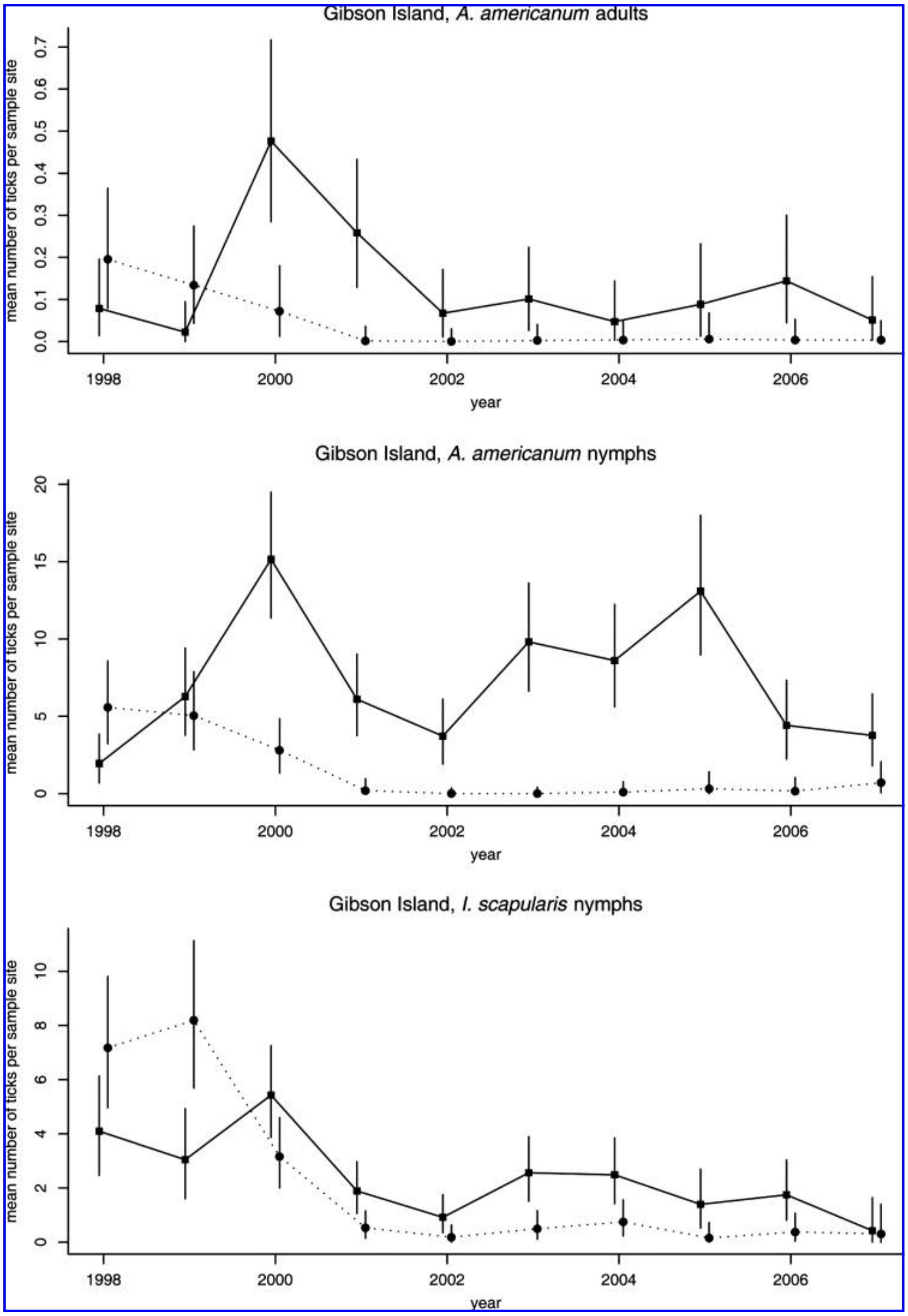
A comparison of nymphal counts for GI from 2002 to 2004 (the period during NEATCP, when major control had been achieved) with those from 2005 to 2007 (when GI Corporation had administered 4-Posters long enough for treatment effects to be manifested in nymphal densities) showed that the change to GI Corporation administration of the 4-Posters had a marginally significant increase in numbers of *A. americanum* nymphs ($p = 0.052$, the actual effect is an estimated increase of only 0.2 ticks per sample site) and no apparent effect on *I. scapularis* numbers ($p = 0.394$). Given that fewer 4-Posters were operated during GI administration (13–15) compared to NEATCP (25) and the natural fluctuations of *A. americanum* populations, as documented at the control site, it is reasonable to conclude that a similar level of tick control was maintained by GI personnel as by NEATCP personnel.

Discussion

Three factors favored a high degree of sustained tick control on GI: (1) limited immigration of tick-bearing large animal hosts, particularly white-tailed deer, from the mainland, (2) unified control of 4-Poster operations under an island residents' association, and (3) all devices maintained by a motivated person who was closely attuned to the local deer population and the island habitat. In 2002, the last year of the NEATCP treatments, an average of only six *I. scapularis* nymphs and one *A. americanum* nymph were captured for all 15 sample sites on GI, over the three sample dates that year (Carroll et al. 2003). These were the lowest densities observed from 1998 to 2007. By comparison, the average captures on the island in 1998 and 1999 exceeded 100 nymphs for both species (Carroll et al. 2003).

From the outset of the NEATCP, the Downs Park (untreated control area) population of *I. scapularis* was never as robust as that on GI (Fig. 1). Not until 2000, when the effect of the acaricidal treatments began to reduce the numbers of host-seeking *I. scapularis* nymphs on GI, did Downs Park counts exceed those on the island. Densities of *I. scapularis* at Downs Park control area remained greater than those on GI, though never returning to 1998–1999 levels.

The graph in Figure 1 may give the impression that the GI *I. scapularis* population may have only experienced a natural decline. Instead, both natural and treatment effects were involved. First (from 1999 to 2000) there was a sharp decline in host-seeking *I. scapularis* nymphs on GI, when counts at the


Gibson Island, *A. americanum* adults

Gibson Island, *A. americanum* nymphs

Gibson Island, *I. scapularis* nymphs

FIG. 1. Mean model estimates and 95% confidence intervals (back-transformed to the original scale) of numbers of *I. scapularis* nymphs and *A. americanum* nymphs and adults captured by flagging are depicted for Gibson Island and the Downs Park comparison area. Fifteen sites at each location were sampled on three dates per year. Dotted line = Gibson Island; solid line = Downs Park.

Downs Park control area increased. Declines in *I. scapularis* counts in 2001 and 2002 were observed both on GI and at the control area, with GI counts remaining lower than those for Downs Park but fluctuating annually in a similar pattern (except 2007 when it was extremely dry). The first decline on GI is consistent with the effects of the 4-Poster intervention. The first year that adult mortality due to 4-Poster treatments would be expected to be manifested in the densities of host-seeking *I. scapularis* nymphs was 2000. This time lag is associated with the 2-year life cycle of *I. scapularis*, with offspring of adults that sought hosts in the fall of 1998 to spring of 1999 seeking hosts as nymphs in 2000. Thus, the 1998 and, to a large extent, 1999 counts represent pretreatment densities.

At the two other MD NEATCP treatment and control locations, the same patterns in counts of *I. scapularis* nymphs, as at GI and its control area, were observed. Counts of *A. amer-*

icanum also declined from 1999 to 2000 at GI (Downs Parks counts increased steeply), and both GI and the control area experienced similar declines from 2000 to 2002. Thereafter at the Downs Park control area, *A. americanum*, in contrast to *I. scapularis*, exhibited substantial annual fluctuations, sometimes exceeding 1998 and 1999 densities.

All NEATCP project locations showed that when the 4-Poster technology was used as specified in the protocol, it effectively and significantly reduced populations of *I. scapularis* and *A. americanum*. However, only at GI was there an opportunity to see how successful the technology would be in the hands of the general public rather than professionally trained applicators and researchers. Comparison of nymphal densities on GI from 2002 to 2004, when NEATCP had achieved a substantial level of control, with densities from 2005 to 2007, when solely GI personnel operated the 4-Posters, showed no significant difference in *I. scapularis* densities and only a marginally significant increase in *A. americanum* densities in 2007 consistent with the natural population fluctuations during that period. More importantly, when administration of the 4-Posters was assumed by the GI Corporation, the tick population remained low for all years sampled.

When 4-Poster operation resumed in 2003 using Dandux-manufactured devices and 4-Poster Tickicide following the hiatus in treatment from late spring 2002, major changes in 4-Poster treatment occurred. Fifteen, instead of 25, devices were deployed, many were relocated, and 10% permethrin formulation replaced 2% amitraz as the acaricide. The absence of treatment pressure, when no intervention occurred, would be expected to result in increased in densities. Because larvae are the most numerous host-seeking life stage and treatments ended before the 2002 larval cohorts of both tick species were active, it is not surprising that some rebound in nymphal densities was observed as early as 2003. However, in succeeding years, the nymphal densities of both species never reached 25% of the pretreatment effect levels, fluctuating instead in the ~10–20% range. The 4-Poster treatments are thought to have the greatest direct impact on adults of both tick species, for which the white-tailed deer is the primary or keystone host.

The change in acaricide (amitraz to permethrin) that accompanied the switch to the Dandux 4-Posters may have had some impact on tick mortality, but it would probably have been mediated by other factors. The 40–48% reduction in the number of devices operated combined with a deer population that more than doubled constitute major differences from the treatments during NEATCP. Suspension of operation of the 4-Posters during winter may have allowed successful feeding of some adult *I. scapularis* picked up by deer on warmer winter days (Duffy and Campbell 1994, Carroll and Kramer 2003). Nevertheless, a notably high level of tick control was maintained.

The history of tick control on GI from 2003 to 2007 exemplifies how 4-Poster technology, in the hands of competent and motivated personnel adhering to a single plan, can be an effective tool in suppressing free-living populations of *I. scapularis* and *A. americanum*.

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Disclosure Statement

No competing financial interests exist.

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