LONE STAR TICKS
Their Biology and Control in Ozark Recreation Areas

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Summary

The lone star tick [*Amblyomma americanum* (Linnaeus)] is distributed from as far west as west-central Texas, north to Missouri, and east in a broad belt to the Atlantic coast, including northern Virginia. The abundance of this pest in some areas, particularly in the Ozark region, has resulted in slow economic development of the affected areas and continues to pose a threat to the economy of such areas.

The long mouth parts of this pest allow deep penetration in the flesh of man and animals during the blood-feeding process. Thus, the bite of this tick is very painful and annoying to infested hosts and "pus sores" frequently occur.

Numerous diseases are transmitted by this tick. Among these are Rocky Mountain spotted fever, tularemia, Q fever, lone star virus, Bullis fever and tick paralysis.

In general, the lone star tick is found predominately in wooded areas, especially in the presence of dense underbrush. In the Ozark region, many hundreds of thousands of acres of "scrub-brush" offer an excellent habitat for this pest. Few, if any, warm-blooded animals and birds are exempt from attack by this tick. The lone star tick must depend on 3 separate blood meals in order to complete its life cycle, and expresses little host preference while in search of these blood meals.

Adult ticks engorge on host blood within about 9 days and after falling from the host may begin laying eggs 5 days later. A female may lay up to 8-10,000 eggs which hatch about 30 days after being oviposited. After hatching, minute larvae, or seed ticks, crawl up nearby vegetation and await an unwary host animal. After a prospective host has become infested by brushing against vegetation convered with these pests, the larvae attach, feed for 3 to 5 days and drop to the ground. Nymphs molt from these fed larvae after 1-3 weeks and seek a host in the manner

decribed for larvae. Nymphs remain on a host for 4 to 8 days, drop, and molt to adults after several weeks. These adults then repeat the cycle which may require up to two years to complete.

Adult and nymphal stages begin to appear in significant numbers and annoy man as early as February. Though adults cease to be a major problem in July or early August, nymphs continue to create annoyance until October. Larvae begin to appear in fair numbers in June and are often present until late October or early November, depending on the temperature. They are most annoying during late July and throughout August.

Environmental factors such as temperature, humidity, amount of overstory or understory vegetation, soil cover or humus, and the existence of large animal populations are important in tick survival and abundance. A definite correlation between host utilization of specific plant communities and tick abundance seems to exist. Where the soil is exposed to direct sunlight for extended periods of time, tick numbers are often very low.

The lone star tick's behavior apparently allows it to seek conditions favorable for greater longevity. For example, migration of up to 95 feet has been reported and larvae avoid dehydration by movements on plants.

Recent emphasis on non-chemical or integrated control of arthropod pests has resulted in an expansion in the testing of less persistent pesticides. One new material, Gardona* (Shell Chemical Co.), has a half-life of approximately 4.5 days on loamy soils and thus poses no long-term residue problem in the vicinity of recreation areas or other aquatic environments. This material is very effective against the lone star tick when applied to recreation areas through the use of various hydraulic sprayers.

Control of unneeded vegetative cover aids in tick population management. Herbicides such as 2,4,5-T OS (Esteron*) are effective in long-term removal of undesired vegetation. Brush removal assists in tick abatement through several routes: (1) Less vegetative browse and/or cover is available to wildlife. This results in lower wildlife usage and reduced reinfestation pressure to the treated area; and (2) Ticks introduced to a treated area are more apt to be exposed to the sun's dehydrating rays and soon perish due to a lack of favorable habitat.

Steps for Recreation Area Tick Control

Based on Oklahoma field studies over the past 3 years, it is felt that the following points should be considered when planning a control program.

Brush control with Esteron — Unnecessary vegetation within parks, along their edges, or along the edges of nature trails should be eliminated. Though this may be done mechanically, several treatments may be required before resprouting is stopped. A number of effective herbicides are available commercially, and can be used. We have found Esteron, 2,4,5 (Dow Chemical Company) to be very effective for this purpose. Brush clearing serves several purposes: (a) it frequently discourages animal visitations and therefore results in fewer new ticks being introduced; (b) it removes protective covering in which lone star ticks may seek refuge while environmental conditions are unfavorable, or when they wish to deposit their eggs; and (c) since many ticks, especially adults and nymphs, depend on brush as an aid in finding host animals, brush removal (i.e. along trails) often pushes ticks back to other vegetation, and attachment to hosts does not occur since animals do not brush against the plant on which the tick is waiting.

Grass clipping — In park maintenance, grasses should be kept under control by periodic mowings. Grasses over 6 in. tall offer considerable protection for ticks against sun and low moisture. There is also the added effect that mowing will dislodge and disperse masses of seed ticks. Once this is accomplished, most will succumb to desiccation. Tall grasses also encourage tick host animal activity since cover is provided.

Overstory vegetation — Removal of all unnecessary overstory vegetation allows greater sunlight penetration and results in higher soil surface temperatures within the park area. Lower humidity can probably be expected to occur and existing ticks will meet with a habitat generally unfavorable for existence. We recommend removal of overstory so that 50 - 80% of the park area soil surface is exposed when the sun is in any one position. Large "clumps" of trees or vegetation should be avoided when possible, since protection for ticks is often afforded in such areas.

Application of Gardona — Gardona should be applied at a minimum rate of 1 lb/A active as a spray when needed to control population build-ups. As a precaution, it is advisable to make two applications of this material per year to insure against visitor exposure to tick attack. One application should be made as the tourist season begins in the spring and should not be made too far in advance of early-summer usage by visitors.

The second application of Gardona should be made near the end of June unless seed tick populations begin to appear prior to the last half of this month.

The need for more than 2 applications of Gardona will seldom occur in well established and well managed parks. Should heavy animal use of the area be noted, the need for additional applications can be anticipated.

Surveys — Flagging surveys as a tool to indicate the need for treatment within recreation areas are often worthless. The reason being that when a very sparse population exists, as often occurs in eastern Oklahoma's parks, flagging surveys fail to indicate a problem. A visitor to the same area, while leisurely passing the time, acts as an attractant. If the visitor tarries too long, the tick will eventually crawl to the source of the attractant and attack the host.

INTRODUCTION

Amblyomma americanum (L.), commonly known as the lone star tick due to the silvery spot on its dorsal surface, has the distinction of being the first tick described in the United States (Bequaert 1945). The first description was given in 1754. In 1739, according to Bequaert, Thomas Salmon wrote the following on the presence and pestilence of the lone star tick in his description of Virginia (See Oudemans 1926):

> **"Seed-ticks and redworms are small insects that annoy the people by day as musqueto's and chinches do by night; but both these keep out of your way if you keep out of theirs; for seed-ticks are nowhere to be met with but in the track of cattle, upon which the great ticks fasten and fill their skins so full of blood that they drop off, and wherever they happen to fall they produce a kind of egg, which lies about a fort-night before the seedlings are hatch'd. These seedlings run in swarms up the next blade of grass that lies in their way, and then the first thing that brushes the blade of grass gathers off most of these vermine, which stick like burs upon anything that touches them . . . "**

Even though two centuries have passed, Salmon's description as recorded above adequately introduces one of the earliest recognized serious pests of man and animals in the United States.

The lone star tick now poses one of the greatest threats to the economic development of eastern Oklahoma and many other parts of the Ozark region. The Ozark region is endowed with water power and manpower matched by few other areas. The "brushy-type" vegetation so common to this region is ideal habitat for the lone star tick and uninhibited populations of this pest have built up over the years to the extent that they are now intolerable in many areas.

The biology and habits of this pest make it difficult to control. Its extensive animal host range, its long spring emergence period and a number of other biological traits help render a portion of its population immune to certain area chemical treatments, regardless of the time of pesticidal application.

Until recently, persistent pesticides (i.e. chlorinated hydrocarbons) offered an appreciable means of reducing lone star tick populations in recreation areas and woodlots of other sorts. Such materials were seldom used on expansive areas for tick control, because most biologists recognized the potential hazards to other organisms in the ecosystem with their use. It is well established that most of these materials are unsuited for use around recreation areas and other aquatic situations where dangers of fish poisoning exits.

Now that the use of DDT and a number of other pesistent pesticides has been greatly restricted, resort managers must rely on other means of control.

Studies were initiated during the summer of 1967 in anticipation of the need for safe, long-term, economical means of control of the lone star tick in recreation areas. The main objective was to demonstrate effective measures that could be taken by park managers to reduce lone star tick populations to within tolerable levels. Data collected during this study, as well as other available information on the biology and control of the lone star tick, are summarized.

Economic Importance

General

The lone star tick is one of the most important tick species in the Ozark region as well as the entire United States. Data indicate that one or more of its three parasitic stages will attack any warm-blooded animal. The long mouthparts of this species are deeply embedded in the host animal and are often broken off when the tick is removed, causing persistent and severe inflammations which frequently end in pus filled lesions. In the eastern and southern states, man is attacked more frequently by *A. americanum* than any other species of tick (Hooker, et al. 1912).

Extremely large populations of this pest occur throughout much of the Ozark region. Dollars lost through devalued land, reduced tourist business, reduced livestock gains, wildlife deaths and incapacitation of man due to tick-borne diseases, are all difficult to estimate. However, public sentiment and interest in alleviating this perplexing problem give us some indication of the magnitude of the situation in eastern Oklahoma and much of the Ozark region.

Data gathered by Oklahoma State University entomologists during the past 2 years indicate that up to 57 percent of all new-born deer fawns (*Odocoileus virginianus*) born within certain areas of the Ozark region are lost because of lone star tick infestations (Bolte, et al., 1970). Other species of wild animals have been observed incapacitated and laden with ticks, but the debilitating effect of ticks has not been ascertained due to a lack of available funds, time, and the complexity of the problem.

Though no published data are available on the effect of lone star ticks on the growth rate of cattle, a recent publication from Australia (Little 1963) showed that a daily infestation of 50 cattle ticks per animal resulted in a growth rate reduction of 83.5 lbs. per animal over 45 weeks time. These figures remind one that from mid-April through July, many beef cattle in eastern Oklahoma support or feed many thousands of adult and nymphal ticks (Figure 1).

Data suggest that perhaps many hundreds of productive workers in the Ozark region are striken annually by one of several debilitating tick borne diseases. The importance of these pathogens in the Ozark region will be expanded on in following paragraphs.

During the tick season, visiting tourists and residents of the Ozark region seldom enjoy a day of recreation without encountering this noxious pest in untreated recreational areas. The lone star tick is capable of inflicting severe bites which are accompanied by extensive inflammation and suppuration (pus lesions). According to Bequaert (1946), in the U. S. man has been plagued by this pest species since at least as early as

Figure 1. An infection of lone star tick nymphs and adults on a beef animal pastured in a typical woodlot pasture in eastern Oklahoma.

1739. In Oklahoma and the Ozark region, most human infestations occur in "rustic" or "primitive-type" recreational areas, game trails, or woodlots in close association with well established recreational areas.

"Gotch" ear in livestock is a condition which can be attributed to the attachment of lone stars within the ears of their hosts (Hooker, et al. 1912). A close relative of the lone star, the Gulf coast tick *(A. maculatum)* is also frequently associated with "gotch" ear.

This tick species, prior to screw-worm eradication, was also a predisposing cause of screw-worm attack.

Human disease vectors

Tularemia, or "rabbit fever" is one of the most serious diseases transmitted by ticks in Arkansas (Tugwell and Lancaster 1962), Oklahoma, Kansas, Missouri and Illinois. These 5 states reported approximately 41 percent of the 1,819 cases occuring in the U. S. between 1959-1963 (McDowell, et al. 1964). In 1969, 148 of the disease cases were reported in the U. S. through December 20 as compared to 157 for 1968 (USDHEW 1969).

Francis (1937) felt that wild rabbits and hares were the source of up to 90 percent of all human cases of tularemia in the U. S. This belief is now known to be without foundation since later reports by Parker, Philip, Davis and Cooley (1937), Washburn and Tuohy (1949), Calhoun (1954), and others have demonstrated that in certain geographical areas tularemia can be considered an "occupational disease" vectored by ticks (Table 1).

The causative organism, *Pasteurella tularensis,* has been passed from stage to stage in the lone star tick (*A. americanum*) under laboratory

Table 1. Occupation of patient and mode of transmission of 704 cases of tularemia reported in Arkansas 1938-48[1].

	Mode of Transmission				
Occupation	Rabbit	Tick	Other	Not Stated	Total
Agricultural worker	61	203	6	29	299
Housewife	75	53	13	18	159
Preschool and school child	43	53	6	8	110
Laborer and lumberman	11	24	1	5	41
Merchant	2	5	1	3	11
Building mechanic	4	7	--	--	11
Other occupations & not stated	11	46	3	13	73
Total	207	391	30	76	704

[1]Abstracted from Washburn and Tuohy (1949).

conditions (Parker, et al. 1937). Isolation of this disease organism by Calhoun (1954) from field collected lone star ticks in Arkansas helped confirm earlier the suggestion by Parker, et al. (1937) and Cooley and Kohls (1944) that the lone star tick could act as a very efficient vector of this disease.

Arkansas had the highest incidence of tularemia of any state with approximately 200 cases per year being reported between 1946 and 1950 (Calhoun 1954). This worker also indicated that 92.8 percent of the ticks collected in a 62 county tick survey were of the lone star variety. In this worker's survey, the lone star tick was the only tick found to harbor the tularemia bacterial organism. The available literature suggests that similar studies on the relationship between tularemia and the lone star tick have not been conducted or reported in Oklahoma.

Very early in this century, Rocky Mountain spotted fever was experimentally transmitted from one animal to another by lone star ticks in the laboratory (Maver, 1911). This researcher fed larvae on an infected guinea pig and was able to show that the resulting nymphs and adults were infected and able to biologically transmit the organism to healthy animals. Parker, et al. (1933) demonstrated the ability of female lone star ticks to pass the causal organism, *Rickettsia rickettsi,* through their eggs to their offsprings, thus rendering the offspring capable of transmitting spotted fever.

In 1942, two different reports were given in which circumstantial evidence strongly incriminated the lone star tick for cases of Rocky Mountain spotted fever in Oklahoma and Texas (Hassler, et al. 1942; Anigstein 1942). One year after these reports, Parker, et al. (1943) recovered the spotted fever rickettsia from field collected lone star tick nymphs in Oklahoma. This finding, along with the considerable circumstantial evidence previously accumulated, positively labelled this pest as a spotted fever vector in Oklahoma and the Ozark region.

Other pathogenic, or potentially pathogenic diseases harbored and which may be transmitted to man by the lone star tick include Q fever (nine-mile fever), Bullis fever, tick paralysis and Lone Star virus.

The rickettsiae responsible for the disease known as Q fever was recovered from lone star ticks in Texas during 1937 (Parker and Kohls 1943). Reports of later isolations of this organism from the lone star tick include that of Philip and White (1955), working in Mississippi.

The condition known as Bullis fever was first recognized at Camp Bullis, Texas in 1941. The lone star tick was the suspected vector since rickettsiae were isolated from patient cases and the lone star tick (USDHEW, 1967). Woodland, et al. (1943), Anigstein and Bader (1943a, b), and Brennan (1945a, b) have further indicated that the lone star tick is probably the sole vector of this disease.

Schwartzwelder and Seabury (1947) associated bites of *A. americanum* with tick paralysis in a young man. Upon removal of 2 partially fed nymphs of the lone star tick from the boy's body, the patient recovered rapidly. Additional support to this potential harm caused by lone star ticks is alluded to in a 1965 USDA publication (ARS 91-49). However, the role of the lone star tick in causing paralysis is not well documented, and the U. S. Public Health Service does not list it as playing a major role in causing this condition (USDHEW, 1967).

Of considerable interest is the recent isolation of a viral agent from *A. americanum* in western Kentucky. Kokernot, et al. (1969) felt that in view of the known medical importance of a number of tick-borne viruses in many parts of the world, additional studies were badly needed to elucidate the disease-producing potential of this new virus, apparently vectored only by the lone star tick.

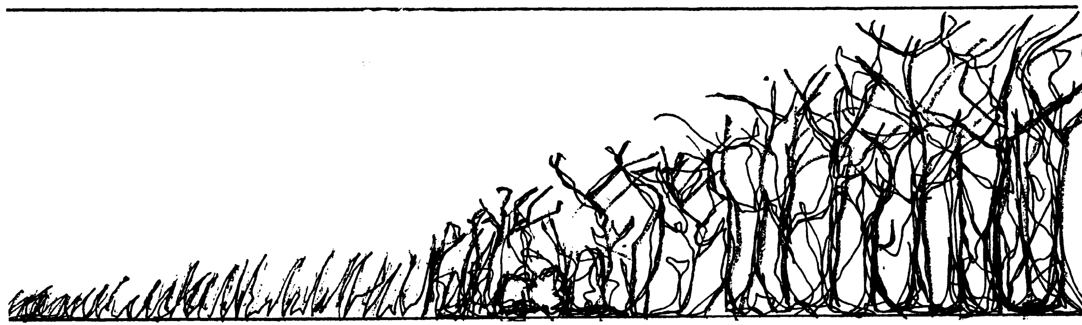
Biology

Distribution

Considerable variation in abundance of this species is encountered within a given geographical region. In general, the lone star tick is found predominately in wooded areas, especially in the presence of dense underbrush. In the Ozark region, many hundreds of thousands of acres of "scrub-brush" offer an excellent habitat for this pest. Concentrations can often be found in less vegetation along river or stream bottoms, hedge rows, or cane brakes (Bishopp and Trembley 1945).

The distribution of this pest within a particular woodlot is quite erratic. Studies in Oklahoma have shown aggregation along the margins of meadows, within forest openings and in certain plant habitat types (Figure 2). Its abundance in these areas is apparently dependent upon host utilization of these habitats. In Arkansas, Lancaster (1957) reported brush to be the habitat of 69.6 percent of all lone star ticks collected. He characterized this type of land as "generally unsuitable for cultivation". The greater abundance of *A. americanum* in wooded areas as compared to grasses-and-herbs areas in Virginia (Sonenshine, et al. 1966) is in accord with the observations of other workers that this species primarily inhabits wooded or brush situations.

The distribution of the lone star tick in the U. S. is from as far west as the brush grows in Texas north to Missouri, and east through most of the New England states. Most early workers expressed the belief that the lone star tick was at one time more abundant in northern states



Tick stage sampled	Grasses			Brush or low trees	Medium trees	Climax forest
	>2 ft	2-4 ft	<4 ft	20 ft	20-40 ft	40 ft +
	Number samples taken					
	63	272	73	39	323	96
	Average number of ticks/sample					
Adults	.8	1.3	1.8	6.2	2.2	.9
Nymphs	4.8	4.4	9.7	146.0	10.9	7.2

Figure 2. Average number of adult and nymphal ticks collected per sample from within or under different vegetative types according to overstory height in Cookson Hills State Game Refuge during June and July, 1969.

such as New York, New Jersey and Pennsylvania than their earlier reports indicated (Hooker, et al. 1912; Bishopp and Trembley 1945). Though infestations or "hot-spots" of the lone star tick are occasionally reported in states other than those shaded in Figure 3, the level of their economic importance is seldom of consequence. Figure 3 was abstracted from Bishopp and Trembley (1945) and represents the probable economic distribution of this pest as we recognize it today. Earlier, however, Hooker, et al. (1912) indicated a distribution extending further north and east, encompassing all the New England states. This species of tick has also been recorded from Mexico, Guatemala, the Guianas and Brazil (USDA 1965), and as far north as Labrador and Manitoba (Parker, et al. 1937).

Hosts

Few, if any, warm-blooded animals and birds are exempt from attack by this aggressive pest. The lone star tick must depend on 3 separate blood meals in order to complete its life cycle. Under field conditions, these blood meals are probably derived from 3 different hosts (Diamant and Strickland 1965). Based on observations in Oklahoma, larvae can be found on host animals as small as the whitefooted mouse (*Peromyscus maniculatus* (W.)) as well as those as large as domestic livestock.

Figure 3. Probable distribution of lone star tick populations of economic importance in the United States.

Nymphs generally are found on hosts as large as, or larger than the cottontail rabbit (*Sylvilagus floridanus* (Allen)), but are occasionally recovered on smaller hosts such as the cotton rat (*Sigmodon hispidus* (S & O)). Oklahoma host surveys involving the examination of approximately 1,000 wild animals revealed that adult ticks preferred, or were most always found on hosts as large as or larger than the racoon (*Procyon lotor* (L.)). The importance of ground-inhabiting birds as hosts for this pest has been discussed by Hooker, et al. (1912), Bishopp and Trembly (1945) and Clymer, et al. (1970).

Table 2 summarizes much of the current knowledge concerning hosts of the lone star tick in the U. S.

Seasonal Abundance — Adults and nymphs

One or more stages of the lone star tick can be found throughout the year in Oklahoma, although numbers may be very scant in late November, December and January. As Figures 4, 5, and 6 indicate, adults and nymphs (yearlings) appear in significant numbers on vegetation during early April. The exact time of a significant increase in activity for these

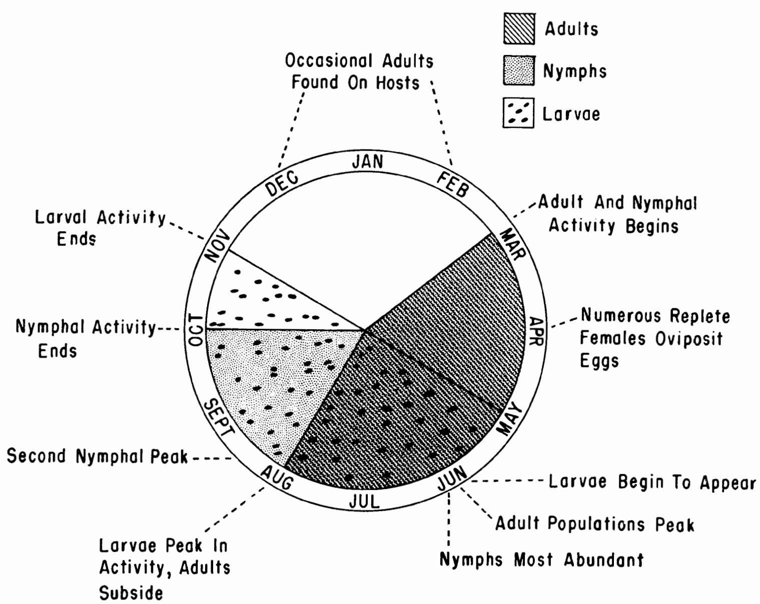


Figure 4. Approximate seasonal activity of the lone star tick stages in Oklahoma and throughout the Ozark region.

Table 2. A summary of U. S. host records for various stages of *Amblyomma americanum*.

Host- Common Name	Tick Stage Larvae	 Nymphs	 Adults	References[1]
Red fox	+[2]	+	+	2
Grey fox	+	+	+	2,1,3,7
Cottontail rabbit	+	+	+	2,1,3,7
Opossum		+		2,3
Fox squirrel		+		2,5,3,6
Striped skunk	+	+	+	2,1,4,3,6
Cotton rat	+	+		2,1,3
House mouse		+		2
Ground hog	+	+	+	2,1,4,3
Racoon	+	+	+	2,1,3
Grey squirrel	+	+		2,1,3,8
Bob cat		+	+	2,4,5,3
White-tailed deer	+	+	+	1,4,3,6,8
Cattle	+	+	+	1,4,3,6,7,8
Horse	+	+	+	1,4,3,6,7,8
Wood rat	+	+		1
House cat	+	+	+	2,4,3,6,7
White-footed mouse	+	+		1
Coyote		+	+	5,3,8
Chipmunk	+			1
Dog	+	+	+	4,5,3,6,7,8
Goat	+	+	+	4,5,3,6,8
Hog	+	+	+	4,3,6,7
Mule		+	+	4,3,6,8
Peccary				4,6
Sheep			+	4,6,7
Man	+	+	+	4,5,3,6,7,8
Badger			+	4,3,6
Wolf	+	+	+	4,3,6,8
Mink	+			4,3
Lion, mountain		+	+	3
Pocket-gopher		+	+	3
Whippoorwill	+			1,2
Chaparral cock	+	+		1,4,3,6
Quail, bobwhite	+	+		1,2,3,4,7
Carolina wren	+			2
Crow		+		2,4,3
Screech owl		+		2
Chicken	+	+		2,3
Wild turkey	+	+		3,4,6
Cardinal		+		3
Meadow lark	+	+		7
Towhee	+	+		7
Brown thrasher		+		7
Wood thrush	+			7

[1] 1 — Clymer, et al. (1970)
2 — Tugwell and Lancaster (1962)
3 — Bishopp and Trembley (1945)
4 — USDA (1965)
5 — Hair, et al., Unpub. data
6 — Hooker, et al. (1912)
7 — White (1955)
8 — Cooley and Kohls (1944)

[2] + = Stage present on particular host

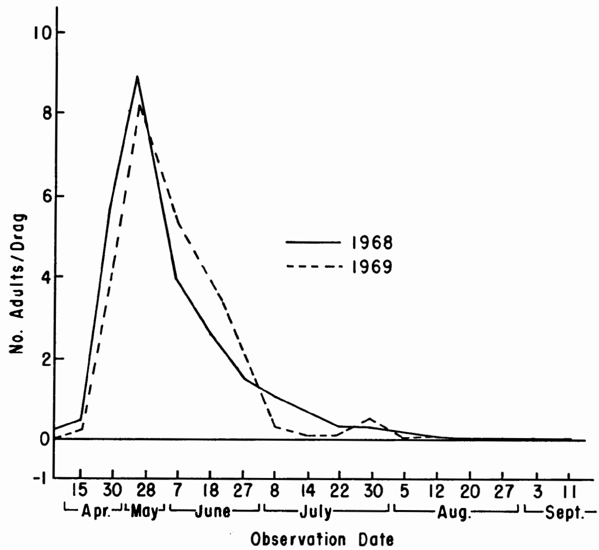


Figure 5. Seasonal distribution of adult lone star ticks on vegetation during 1968 and 1969 in Cookson State Game Refuge, Cherokee County, Oklahoma.

two stages in central Oklahoma depends, to a great extent, on mean and maximum daily temperatures. Photoperiod, or day length, may also play an important role in stimulating activity, but based on other ecological observations, i.e., finding adults on hosts during December or January, it seems likely that increases in temperature stimulate activity, regardless of photoperiod (Figure 4).

In southeastern Oklahoma, activity of adults and nymphs begins as much as 2 weeks earlier than is indicated in Figures 5 and 6. If temperature is the stimulating factor, one might then expect peaks in areas of Texas to occur in April. Results by Drummond (1967) obtained during the spring of 1961 showed this to be true for both adults and nymphs. Further observations by Drummond (1967) during other years closely approximate those made in Oklahoma on the seasonal distribution.

In Oklahoma, and throughout the Ozark region, complaints of tick attack on man are received as early as mid-February. During late March and especially early April, tremendous numbers of adults and nymphs can be found actively crawling over the leaf litter in woodlots. During this time period, few ticks are found on vegetation, and consequently surveys by flagging often fail to give an accurate indication of "active" ticks in the area sampled. As temperatures increase in early April, a large percentage of the "active" population is found on vegetation and appears to be more aggressively seeking a host. Although extensive observations have not been made on the association between adults and nymphs and the forest floor duff during these cool days in March and April, it has been observed that these stages may retreat to the cover of the "duff" if temperatures drop below a specified level. Subsequently, as the temperatures rise and the danger of exposure has passed, less association with the duff is required allowing for more freedom to venture greater distances in pursuit of a host.

Surveying host animals for tick infestations seems to provide a better indication of the beginning of lone star tick activity in the Ozark area than does flagging methods. It appears that increases in numbers on animals can be detected prior to a rise in activity as indicated by flagging.

Lone star nymphs and adults appear in February on animals in Arkansas after an apparent absence during December and January (Tugwell and Lancaster 1963). This study indicated that peak numbers of these 2 stages are reached during May. Data collected in Oklahoma (Clymer, et al. 1970; Hair, et al. unpublished data) agree with that presented by Arkansas workers.

The seasonal abundance of lone stars in Missouri (Portman 1945) indicates that adults are most active during the latter part of May and

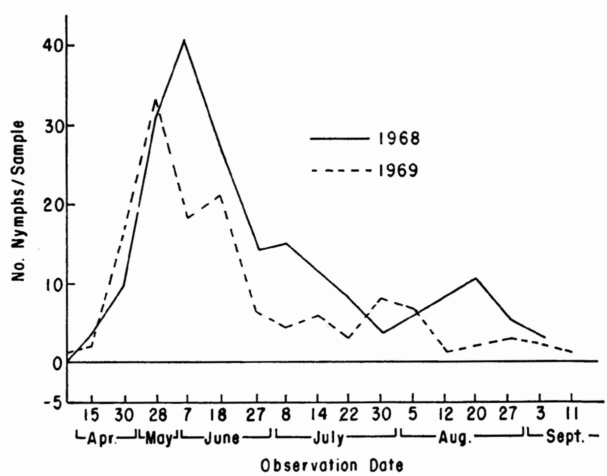


Figure 6. Seasonal distribution of nymphal lone star ticks on vegetation during 1968 and 1969 in Cookson State Game Refuge, Cherokee County, Oklahoma.

early June. This is almost one month later than what has been reported in Arkansas and Oklahoma (by flagging methods), but Drummond (1967) in Texas indicates similar peaks for May and June. Reports from Virginia (Sonenshine, et al. 1966) indicate peaks during May or June for the eastern-most infestations of this pest. The earliest appearance of adults in Virginia is mid-March and nymphs are reported to appear about mid-April (Sonenshine, et al. 1966). In Florida, lone star adults are most abundant from January through March (Rogers 1953).

Adult tick activity in Oklahoma generally subsides by late July and only occasionally is an adult encountered before the following spring. Nymphal activity decreases rapidly in late August, but a few specimens are found in October. No nymphs were reported in Arkansas by Lancaster (1957) in October.

Nymphal activity appears to be bimodal in all geographical areas; that is, two distinct peaks in activity occur. These peaks are in late May or early June and early August in Oklahoma.

Seasonal Abundance — Larvae

Lone star larvae, or "seed ticks", seldom appear in appreciable numbers in Oklahoma until mid-June (Figure 7). Reports of the presence of larvae as early as June 10 have been reported by Lancaster (1957) and one mass of lone star larvae was taken in Oklahoma on May 28, 1969 (Hair, et al. unpublished data). Larvae first appear in Virginia in June or July (Sonenshine, et al. 1966). June 15 was given as the hatching date for larvae in Missouri (Portman 1945). The greatest number of larvae was found in Oklahoma on August 1, in 1968 and July 29 in 1969. In his Arkansas studies, Lancaster (1957) noted a larval peak in August.

Sometimes nearly intolerable numbers of larvae remain quite abundant through September in Oklahoma and Arkansas. Samples taken during November have shown light activity of larvae in Oklahoma (Howell and Hair 1969).

Life History

Two of the most complete studies on the life history of the lone star tick are those by Hooker, et al. (1912) utilizing both laboratory and field studies, and Loomis (1961) which was performed entirely in the laboratory. Many other workers have contributed biological notes on this species.

Engorged females seldom appear on hosts before mid-March in Oklahoma, but replete females have been reported as early as February 19 in the Ozark region (Lancaster 1957). In Oklahoma, maximum numbers of fed females are observed dropping from domestic livestock and deer

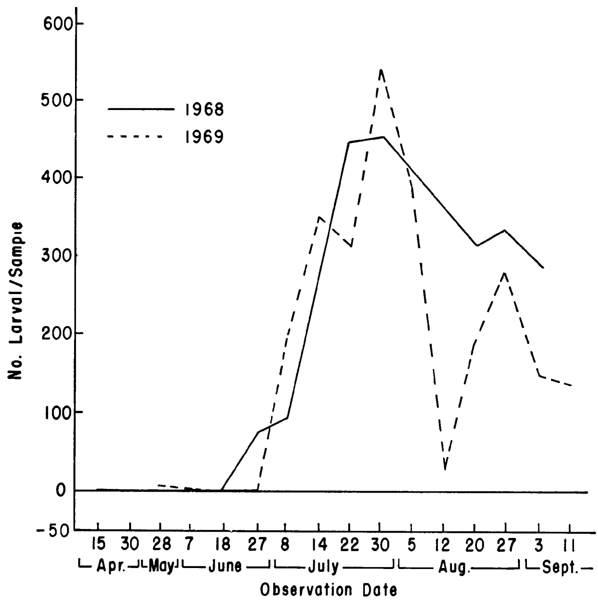


Figure 7. Seasonal distribution of larval lone star ticks on vegetation during 1968 and 1969 in Cookson State Game Refuge, Cherokee County, Oklahoma.

during late April, May and early June. The females seek seclusion under available soil litter and deposit their eggs after a lapse of 5 to 16 days, depending on average daily ambient temperature. The number of eggs deposited is frequently over 5,000 per mass. Oviposition was reported within 5 days at 87.7° but at 81°F it required at least 2 more days (Hooker, et al. 1912). At 70-78°F, the laboratory preoviposition time varied from 7 - 16 days (Loomis 1961). Observations in the laboratory at Oklahoma State University indicate an average preoviposition period of 10 days (Hair, unpublished data).

Oviposition behavior of lone stars under field conditions has not been recorded, but Hixson (1940) reports that in the Gulf coast tick (*A. maculatum* (Koch)), a close relative, the egg mass is generally deposited on the surface of the soil. Hixson also indicated that the female occasionally prepares a shallow excavation in which the eggs are deposited. Incubation of lone star tick eggs under field conditions is generally about 30 days but may be temperature dependent. For example, eggs deposited on April 12 required 63 days for hatching in contrast to those deposited on June 10 which required only 25 days. Those deposited on September 27 hatched 109 days later (Hooker, et al. 1912).

Oviposition site preference is not known. However, it would be advantageous for eggs to be deposited near suitable vegetation to insure a suitable resting site for the emerging larvae.

Some newly hatched larvae feed almost immediately and up to 90 percent have been observed to attach to a host before they are 5 days old (Gladney, personal communications). Average larval feeding time at 80°F (Hair, unpublished data) is 4 days. This agrees with the observations made by Lancaster (1957) and the range of 3 - 7 days reported by Loomis (1961). Notes on larval behavior in the field are scant. Our observations indicate that once larvae localize themselves on vegetation, they will not make extensive vertical migrations (from the forest duff to the top of the plant) as has been observed in the sheep tick (Milne 1946). Our observations indicate only two basic movements by larvae: (1) responses to directional sun rays in which they make every attempt, even in partially shaded areas, to avoid positioning themselves on the plant surface facing the impinging sun rays; and (2) minor vertical movements stimulated by heat from the body of a prospective host. Larvae are less responsive to carbon dioxide than nymphs or adults (Hair, et al. unpublished data).

Heavy rains and strong winds tend to dislodge seed tick masses, and under such circumstances less than 10 percent of the mass has the ability to regroup. The remainder are apparently lost.

Nymphs molt from replete larvae 9 - 27 days after having dropped from their host (Loomis 1961; Lancaster 1957; Hooker, et al. 1912). We have noted very little molting (in the laboratory) in less than 2 weeks at 80°F and 80 percent relative humidity. Approximately 75 percent of the nymphs require at least 7-9 days before they will attach to a host animal.

Field observations indicate that nymphs overwinter in both the fed larval stage and unfed nymphal stages. Lancaster (1957) has noted the overwintering of unfed nymphs. Hooker, et al. (1912) indicates that winter temperatures considerably extend the molting period and lists a total effective temperature of 350°F as that required to induce molting from the larval to the nymphal stage.

Hooker calculated the effective tempertaure in the following manner: (1) days with a daily mean temperature below 43°F were ignored; (2) 43°F was subtracted from those daily means above 43°F; and (3) the differences in (2) were added (Hooker, et al. 1912). Taking this information into consideration, larvae falling from hosts during September, October, and November should molt either during the winter months, continue development as larvae, or emerge in the spring some time after older overwintering replete larvae.

Adults overwinter in two forms: unfed adults or replete nymphs that become adults during the winter after exposure to adequate warmth. Hooker, et al. (1912) felt that a total effective temperature of 657°F was required to transform replete nymphs to adults. This implies that 66 days with a mean temperature of 10°F over 43°F is required for molting. Lancaster (1957) also suggested that molting of overwintered, engorged nymphs is dependent on seasonal temperature.

Theoretically, using Hooker's theory of mean effective temperature, replete nymphs held at 80°F should molt after 18 days exposure. In reality, this method of calculating possible molting time appears to be accurate. At approximately 70 - 79°F, Loomis (1961) found that 14 to 19 days were required for molting. Lancaster (1957) indicates a molting time of 21 days, but failed to give the holding temperature.

In the Ozark region, we normally encounter large numbers of nymphs and adults which have passed the winter as either replete larvae or nymphs, or as unfed nymphs and adults, during the month of March. At this time, however, they are not as aggressive as those encountered in April, May or June.

Occasional larval masses appearing in May and early June are likely the offspring of females encountered on hosts as early as February and March. As Figures 5 and 7 indicate, approximately 3 months pass from the time of peak adult activity until a peak in their offspring occurs in Oklahoma. During this time, a host must be found and a blood meal

Table 3. A summary of the life history of the lone star tick in several different U. S. laboratories.

Developmental	Stage or period duration (days)				
Stage or Period	Lancaster[1]	Loomis[2]	OSU Lab[3]	Hooker[4]	ARS[5]
Egg incubation	25	24-31	27-35	23-117	23-117
Pre-feeding, larval	10	7-14	2-4	3+	
Larval feeding time	4	3-7	3-5	3-9	3-9
Larval stage after feeding	12	9-27	12-30	8+	8-26
Pre-feeding, nymphal	10	4-6	3+	3+	
Nymphal feeding time	4	3-6	5-6	3-8	3-8
Nymphal stage, after feeding	21	14-19	10-25	13-46	13-46
Pre-feeding, adult	10	3-6	6+	9+	
Adult feeding time	6	10-16	7-15	11-24	9-24
Time before oviposition	8	7-16	8-10	5+	5-13
Oviposition duration	11	[6]	7-12	9-14	7-28

[1] Lancaster (1957); Temperature not stated.
[2] Loomis (1961); Temperature 70-78°F.
[3] OSU Laboratory, unpublished data; Temperature 80°F, 80% RH.
[4] Hooker, et al. (1912); Variable temperatures.
[5] ARS (1965); Temperature not stated
[6] Data not available.

taken, followed by detachment from the host. A suitable oviposition site must be found for egg laying and incubation. The emerging larvae then locate and ascend suitable vegetation.

Larvae exposed to outdoor environmental conditions in glass tubes have survived for 279 days (Hooker, et al. 1912) but do not survive the winter in Oklahoma under field conditions. The longevity of nymphs has been reported as 476 days but in the case of adults this is reduced to 400 - 425 days (Hooker, et al. 1912).

Observations in Oklahoma indicate that the average longevity of adults under field conditions is less than 75 days and for nymphs less than 100 days. Dead adults have been observed in mid-July, still clinging to their host plant where they patiently waited for a host that never arrived. During this same time period, aggregation of nymphs occurs and could possibly be a biological response to unfavorable temperatures and/-or low available moisture. Shortly after such aggregation (Figure 8), nymphs reach a mid-season low (Figure 6). More "clumping" of adults is found at this stage of their seasonal distribution than at any other time.

Environmental Factors Influencing Survival and Distribution

Temperature and humidity

Development, activity and survival of the lone star tick are influenced greatly by the temperature and humidity within the tick's micro-habitat. Our knowledge of the sense organs which ticks use to seek and occupy areas of optimum temperature and humidity is scant. One of the earlier papers that mentions some of the possible ways that these environmental factors affect the lone star tick was that of Hooker, et al. (1912). For example, these workers noted that at the mean daily temperature of 87.7°F, oviposition commenced as early as the fifth day after repletion, whereas at 81°F, seven or more days were required prior to the initiation of oviposition. At 80.5°F, eggs hatched as early as 23 days, but required up to 117 days at an average daily temperature of 56°F.

Additional information collected in the field on the role of these two environmental factors on abundance and distribution of *A. americanum* is very scant and in general offers only rough estimates of the tick's requirements. This is partially due to a current lack of small, inexpensive, portable equipment capable of measuring the micro-habitat. A hygrothermograph and aspirated psychrometer were used by Lancaster and McMillan (1955) to measure relative humidity at the ground level under various cover. It is doubtful that data collected under these conditions and with the use of such equipment accurately determine the micro-habitat requirements of the lone star tick. For example, the base of the sensing element in a hygrothermograph is approximately 1 in. from the surface on which it is resting and the upper end of the element is as high as 6 inches from the soil surface. Such instruments will give only gross atmospheric measurements. In the opinion of the authors, such measurements cannot be used with a high degree of confidence in judging the suitability of a particular area as a tick habitat. Since micro-habitat, on vegetation, and within forest floor duff, differs drastically from the surrounding atmosphere, it is the former areas that we must strive to measure in characterizing the "house in which ticks live".

Humidity

Knowledge that a minimum relative humidity is required for the development of ticks stems from numerous publications (Lees 1946; Feldman-Muhsam 1947; Lancaster and McMillan 1955; Lancaster 1957; Knulle 1965; and Snow and Arthur 1966). Lancaster (1957) found that only lone star tick eggs reared in an environment of approximately 75 percent or above laboratory humidities hatched. Lancaster also found that females oviposited faster at higher humidities and that eggs took more time to hatch at higher suitable humidities.

In an excellent paper by Lees (1946) it was shown that another hard tick, *Ixodes ricinus* L. (the sheep tick), lost 50 percent of its original weight within a period of 24 hours if kept in a container of 0 percent relative humidity, and died within 24 hours. At 50 percent RH, only 10 percent of the orginal weight was lost per day and the arthropod generally lived for 3 - 5 days. Rearing in 70 percent humidity caused only 5 percent water loss per day and survival increased to 4 - 8 days. Significantly, ticks survived for 2 - 3 months at 90 percent RH because water from the cuticle was not given up to the highly humid atmosphere.

Feldman-Muhsam (1947) showed that *Hyalomma savignyi* Gerv. ticks survived only a few days at 20 percent humidity and 17.5°C, but were alive after approximately 7 months when held in an atmosphere of 95 percent relative humidity.

Attempts are now being made in Oklahoma to better estimate the humidity or duff moisture found in areas where ticks occur.

Temperature

Telethermometers with recorders and probes now make it possible for us to record, with considerable accuracy, the temperature on the surface of vegetation, and at any depth within the soil profile. Such recording devices are relatively new and field microhabitat temperature data are not available in any known published reports. Once more, laboratory data provide us with the best information concerning the influence of temperature on the various life stages of ticks.

The tick *Hyalomma savignyi* survived less than 3 weeks at laboratory temperatures of 37°C, $2\frac{1}{2}$ months at 30°C and about 7 months at 17.5°C (Feldman-Muhsam 1947). It was noted in these studies, however, that relative humidity was more important than temperature in determining survival time. We can speculate that this could also be true for the lone star tick under field conditions. For example, we have noted a reaction on the part of larval masses to avoid desiccating sun rays. This is accomplished by moving around the piece of vegetation on which they are resting until they are on the opposite side of the leaf away from the sun's rays. However, masses of larvae on grasses experiencing severe drought soon perish in eastern Oklahoma. Such mortality generally occurs very late in July or August, and the extent of mortality appears to depend on the amount of summer rainfall. Such mortality is great enough to possibly account for an overall drop in abundance during late-July or early-August (Figure 7) when temperatures are most extreme.

Adequate moisture within the tick's micro-habitat is likely maintained as long as the plant is in good physiological condition and transpiring properly. The moisture in the microenvironment of dying or dead plant tissue when soil moisture is scarce is probably much less than that found surrounding healthy tissue, and is probably insufficient to meet the requirements of the lone star tick. Additional studies and measurements are currently underway in this area. In circumstances such as those just described, it seems that hot dry air soon dries away most moisture falling as mid-summer rains, and at least in this respect, plays an important part in the longevity of the existing tick stages.

Detailed discussions on the effects of temperature on survival of ticks have been essentially omitted from a number of excellent papers in which humidity effects have been reported (Hixson 1940; Lancaster and McMillan 1955; and Lancaster 1957).

Most eggs of *Hyalomma aegyptium* ticks were deposited between 20° and 35°C; very few were laid at 15°C and none at all at 40°C (Sweatman 1968). It was also observed in this species that at 30 - 35°C the maximum rate of egg deposition was reached. Longevity of this species was reduced with an increase in temperature. *Rhipicephalus sanguineus* and *Boophilus microplus* deposit more eggs at a faster pace when held at 20°C than at 15°C (Sweatman 1967; Hitchcock 1955).

High temperatures and a lack of moisture are thought to be responsible for adult and nymphal aggregation (Figure 8) during periods of hot, dry weather during July and August. Further studies may show,

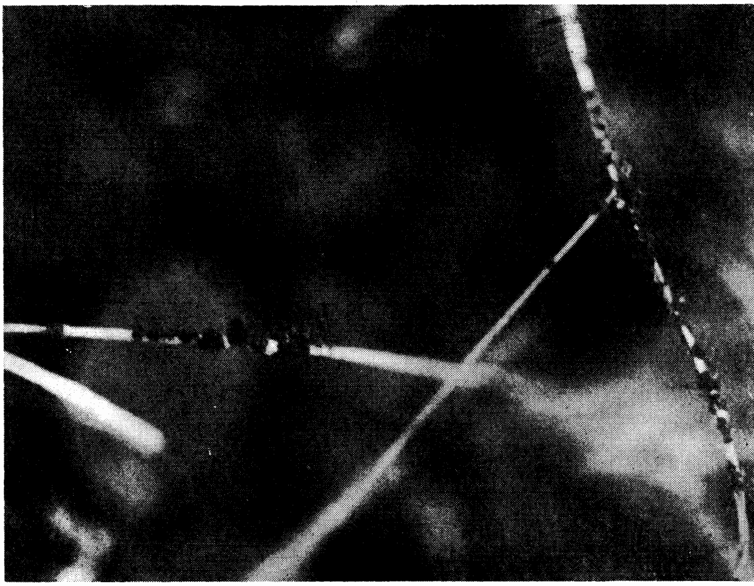


Figure 8. Adult and nymphal "aggregation" in an Oklahoma woodlot area. Such behavior perhaps helps extend their longevity under unfavorable environmental conditions.

however, that these aggregates are masses of newly molted individuals which will, if the cycle proceeds normally, take a blood meal or overwinter.

Much is yet to be learned of the temperature and humidity requirements of ticks under field conditions and how they have adapted, or behave, to meet these requirements. It is rather difficult to apply laboratory findings to field conditions when considering these 2 important environmental factors. This can be attributed to many complicated interactions which exist between temperature and humidity and with other environmental or behavioral factors.

Semtner (1970) has noted in Oklahoma that greater exposure to the sun on the east, south, and west sides of a forested area results in a smaller population of ticks. The east and west sides receive even less exposure than the south and consequently a few more ticks were generally found in these areas (Table 4). More exposure to direct sun rays generally results in higher temperatures, and over a period of time, less humidity in the environment.

Vegetative and Organic Ground Cover

One reason it is difficult to apply laboratory findings concerning temperature and humidity to a field tick population is that ticks are

Table 4. **The effect of shading on tick numbers in the forest transitional zone based on the position of the zone in relationship to the main forest, Cookson State Game Refuge, June and July, 1969.**

Position of ecotone	Number Samples[1]	Average # ticks/sample	
		Adults	Nymphs
East	32	2.3	6.5
South	62	1.8	5.5
West	30	3.2	5.4
North	52	3.9	13.6

[1] A sample was a 25 yard^2 area.

generally confined to cages of various sorts within the laboratory and are unable to escape or modify, through behavior, the environment to which they are exposed. We know that lone star ticks have considerable migratory potential, (Smittle, et al. 1967) and theoretically, if they dislike one area due to environmental conditions, they may move until they find conditions favorable for their survival. Therefore, given a particular reasonably-sized area containing meadow, brush, tall grasses, various sized trees and mixtures of these various plants, it is possible that *A. americanum* could seek the "zone" of vegetation most suitable for survival and host-finding. We know that the American dog tick does just this (Smith, et al. 1946). We find a build-up of the lone star tick associated with particular vegetative types (Tables 5 and 6; Semtner 1970) and have postulated that this is due to one, or more of the following: (1) host utilization of those areas heavily infested with ticks is much greater than in surrounding areas; (2) environmental conditions within these areas are more favorable than in surrounding areas and consequently build-up is due in part to greater longevity once the ticks are introduced; (3) some migration to these "hot-spot" areas does occur due to the ability of this tick species to sense and seek areas heavily utilized by their hosts, or that environmental conditions are more favorable within the new area than where they are now existing; or (4) a combination of factors 1 - 3. Several of these items have also been proposed by other workers (Lancaster 1957; Smittle, et al. 1967; Sonenshine, et al. 1966; and Hooker 1908).

Open meadows or prairies were shown to support fewer ticks than other habitats in Oklahoma with perhaps the exception, in some cases, of climax forests (Figure 2). In general, brush and low trees supported at least three times as many adults as surrounding areas and nymphs were some 15 times more prevalent than in adjacent habitats.

In the same study, persimmon-sassafras woods were found to harbor tremendous numbers of nymphs (Table 6). A possible explanation for this phenomenon is that during the previous year, much time was spent in persimmon-sassafras groves by the hosts of tick larvae. We know that deer, an important host, as well as a number of omniverous animals, normally spend many hours seeking the fruit of the persimmon during early fall. Such hosts are commonly infested with larvae during the early fall. Sassafras of the persimmon-sassafras forest is also a highly preferred plant browse species by deer. One wonders if browsing in the area by deer is sufficient to encourage tick migration into the areas, but the former explanation of being introduced by the host is perhaps more reasonable.

Table 5. Association of *Amblyomma americanum* with specific vegetative habitat types found within woodlots during 1969, Cherokee Co., Oklahoma[1].

Plant	Number Samples	Males	Females	Combined Males and Females	Nymphs
Broomsedge	50	2.7	2.7	5.4	22.0
Buckbrush	68	1.3	1.4	2.7	38.5
Tick clover	31	3.2	4.6	7.8	8.9
Broad-leaf unolia	34	.2	.5	.7	3.0
Panicum spp.	19	.7	.8	1.6	7.0
Saw greenbrier	12	.8	.7	1.5	15.8
Dropseed	10	.4	.3	.7	16.2
Sericea lespedeza	10	.3	.8	1.1	14.1
Wild rye	4	2.3	1.5	3.8	6.0
Johnsongrass	3	2.3	2.3	4.7	17.7
Blackberry	2	6.5	6.5	13.0	18.5

[1] From Semtner (1970).

Table 6. The average number of ticks per sample[1] found in different habitats in Cookson Hills State Game Refuge, Oklahoma, during June and July, 1969[2].

Habitat of Community	No. of Samples	No. Ticks/Sample	
		Adults[3]	Nymphs
Open prairie	344	.2	.86
Forest prairie ecotone	177	2.8	8.50
Openings in woods	45	4.5	24.10
Woods:			
Persimmon-sassafras	83	4.0	68.40
Post oak-blackjack oak	97	2.7	16.80
Oak-hickory	234	1.9	8.90
Total woods	414	a.4	22.40
Other	30	1.0	3.4

[1] A sample is the actual number of ticks collected per 25 yards^2.
[2] From Semtner (1970).
[3] Sex ratio male: female; Approximately 1:1.25.

The brushy area along a forest edge almost always contains many more ticks than are found in an adjacent habitat. Smittle, et al. (1967) showed that when lone star ticks were released adjacent to shaded areas, the predominant direction of migration was toward and into shaded areas. These workers observed migrations up to 75 feet in 72 hours. It is probable that if a climax forest area is as unsuitable a tick habitat as open meadow (Lancaster 1957; Semtner 1970), migration to, and aggregation within the ecotone (brushy area) partially explain the build-up in this area. On the other hand, we also realize that the area provides a better wildlife habitat because of the abundance of food and cover. Greater utilization by wildlife means greater tick reinfestation pressure and as indicated by Smith, et al. (1946), could also mean that animal odors and activity cause tick aggregation into the area.

That density of undergrowth plays a part in maintaining certain stages as well as numbers of *A. americanum* have been demonstrated in Oklahoma (Semtner 1970). This information is summarized in Table 7. When comparing areas with less than 25 percent undergrowth cover to those with more than 75 percent the former was found to support nearly twice as many nymphs and only two-thirds as many adults.

Quantity of leaf litter within woodlots seems to have just the opposite effects on nymphal abundance when compared to adult tick

Figure 9. A typical infestation of lone star ticks on a white-tailed deer in Cherokee County, Oklahoma.

abundance. That is, nymphs were almost 3 times more abundant in deep litter than in areas sparcely covered, whereas, adults were more prevalent in higher litter (Table 7).

To be able to correlate numbers of ticks with a particular physical trait of a woodlot creates additional questions on the complicated biology of this species. We can speculate that heavy brush frequently means more spring and early summer browse for deer, a principal host animal, the introduction of large numbers of replete nymphs and adults to these bushy areas, and thirdly that many adults arise from these overwintering replete nymphs the next year. This hypothesis is supported by the data in Table 8. Further, we postulate that later in the season when browse is tough, greater movement of larval tick-infested deer occur in pursuit of browse. This would mean fewer nymphs the next spring in the ecotone when this area was compared to the less brushy areas.

The association of tick stages and numbers to density of leaf litter is difficult to interpret and further observations will probably be required before we understand the total role of these physical factors in survival and longevity of the lone star tick.

Table 7. A comparison of the tick density with the density of the leaf litter in woodlots in Cookson Hills State Game Refuge, Cherokee Co., Oklahoma, June and July, 1969.

Litter Coverage[1] (%)	Number Samples	Average No. tick/sample[2]	
		Adults	Nymphs
< 25	47	3.9	13.5
25-75	188	2.3	30.6
> 75	110	1.8	27.0

[1] Expressed as an estimate based on the assumption that 100 percent coverage would mean an entire blanket of litter within a particular area.
[2] A sample was a 25 yard^2 area.

Table 8. Numbers of adult and nymphal ticks associated with various densities of undergrowth in Cookson Hills State Game Refuge, Cherokee Co., Oklahoma, June — July, 1969.

Undergrowth Density[1] (%)	Number Samples[2]	Average No. ticks/sample	
		Adults	Nymphs
< 25	200	2.2	26.0
25-75	190	2.4	20.4
> 75	48	3.1	13.4

[1] Expressed as an estimate based on the assumption that 100 precent coverage would eliminate sun-ray penetration to the forest floor.
[2] A sample was 25 yard^2 area.

It is interesting that the tick's geographical distribution is generally closely associated with the presence of rough, sometimes dense scrub underbrush.

Behavioral Traits Of The Lone Star Tick

Three behavioral patterns of the lone star tick have been mentioned in previous sections. These were migration (movement) to avoid unfavorable habitat, reaction of larvae to impinging sun rays by repositioning themselves on vegetation and aggregation of adults and nymphs during July and August, possibly as an effort to conserve moisture. Smittle, et al. (1967) has elaborated on item one (migration) as a possible means of reaching shaded areas. Wilkinson and Wilson (1959) have shown that shading prolongs the life of cattle tick (*Boophilus microplus* (Canestrini)) larvae, and Semtner (1970) has shown that dispersal of lone star tick larvae results in extensive mortality, possibly due to desiccation. Therefore, aggregation by nymphs and adults leads one to believe that this also is a protective response to unfavorable environmental conditions.

Marikovskii (1945) and Balashov (1960), have extensively studied the migration of *Dermacentor silvarum, Haemaphysalis concinna,* and *Ixodes persulcatus* in pursuit of hosts, or host habitats. Balashov made the following notes on *Hyalomma asiaticum* ticks: (1) with a gradual increase in average diurnal temperatures and "burning" of vegetation, ticks concentrate around trees, large shrubs, rodent burrows, and other shelters, thus providing shade from direct sun rays. Owing to their remarkable mobility, hungry ticks are able to cover a distance of several meters in search of a suitable microbiotype; (2) during relatively cool days, ticks actively pursue hosts throughout the entire day, but when diurnal air temperature increases to 30°C and the soil to 45 - 50°C, maximum tick activity was restricted to the morning (dawn 'til 10 A.M.) and evening (6 P.M. 'til nightfall).

The above examples of behavior illustrate the point that some tick species have behavior and habits which render them less vulnerable to the elements when adverse conditions exist. *Amblyomma americanum* behavior has been studied very little.

Some resemblance in behavior to *Hyalomma asiaticum* is shown in that *A. americanum* probably detects and behaviorably avoids adverse temperatures to escape death. In the early spring (March and April) adults and nymphs are frequently observed in close association with forest floor litter. At this time, even in "hot spots" where thousands of ticks are active on the duff, few are found up on the vegetation. It is believed that by staying in close association with the leaf litter, adults and nymphs avoid cool night temperatures by seeking protection in the litter, since with the advent of warmer weather the same ticks soon ascend vegetation. As daily mean temperatures continue upward and the likelihood of freezing decreases, ticks become more active.

Larval behavior to avoid desiccation has been elaborated on previously. It is likely that the behavioral responses to micro-habitats of humidity conserve considerable amounts of water for tick larvae.

Host seeking in lone star ticks exist in three forms: (1) ascending vegetation in anticipation of a host brushing them off as the host passes; (2) actively "hunting" the host by migration on the forest floor; and (3) a combination of 1 and 2. Many thousands of adults and nymphs ascend vegetation and anxiously await the arrival of a suitable host. Generally this approach to the finding of a host depends entirely on the host making contact with the ticks as they rest on the tips of plants. It has been observed in our studies that if man or other hosts approach the vegetation on which adult lone star ticks rest, and remain in the area for a considerable time, adults will be stimulated by heat and carbon dioxide from the host's body and become highly aggressive and frequently fall to the ground. Once the adults are on the ground surface, they will then, in time, proceed to locate the host and mount the animal.

Those ticks normally occurring on the forest floor and which have not ascended vegetation, may move considerable distances to find a host. For example, carbon dioxide is a by-product of animal respiration and an effective attractant for lone star ticks (Hair 1969; unpublished data). Nymphs and adults will sometimes be attracted from the surrounding duff in large numbers in an effort to locate the source of carbon dioxide. It is assumed that many hosts are infested while bedding at night.

The desire of adult ticks to locate a host often compels them to remain on vegetation until they perish. Dead females in the "awaiting" attitude have been frequently located on vegetation. These observations have been made in July.

Larvae seldom "seek" a host but depend almost entirely on the host to make contact with the larval mass as it hangs on the tips of vegetation.

Lone stars are negatively geotropic; that is, once a host animal or plant is located, they normally crawl upward. This probably accounts for the heavier concentrations of ticks about the head on some hosts (Diamant and Strickland 1965; Bishopp and Trembley 1945). Larvae are generally found near the top of their host plant or on the peripheral edges of leaves. Adults and nymphs generally follow the same pattern on larger plants. This adult and nymphal behavior puts them at a height which probably prevents them from being brushed off by a small, unsuitable animal.

Mating occurs on the host animal, after both sexes have begun to feed. The male feeds for at least 6 days prior to detaching and seeks a female on the same host animal. Laboratory studies in Oklahoma have shown that males frequently mate with several different females. The method used by males in locating a female is unknown. Random chance might result in female location, or, the female may expel a sex attractant after she has fed for a reasonable length of time. After feeding for several days, males can be observed actively migrating over the host animal's body in pursuit of a mate.

Control Within Recreation Areas

Control of the lone star tick was discussed by Hooker, et al. (1912) who stated: "Owing to the greater longevity of the nymphs and adults, and to the many hosts which this species attacks, the rotation (referring to pasture rotation) method of eradication is impracticable."

Much progress in the area of pest control has been made since the 1912 publication by Hooker, et al. Shortly after DDT became commercially available in this country, it was shown that up to 97 percent control of ticks could be obtained by applying this material to tick-infested vegetation (Smith and Gouck 1944). This insecticide is no longer acceptable for use in woodlots, especially near recreation areas because of the danger to wildlife.

With today's increased emphasis on non-chemical procedures for suppressing arthropod pests, an urgent need for an integrated tick-control program in recreation areas, adaptable throughout the U. S. as well as the Ozark region, was envisioned several years ago. Work was expanded in Oklahoma during 1967 to investigate the integrated approach to lone star tick control in recreation areas.

In 1944, when workers (Smith and Gouch 1944a) were conducting some initial tests with insecticides for field control of *A. americanum* on vegetation, even materials such as sodium fluoride and nicotine sulfate were used. Surprisingly, good control of ticks were obtained, but this material was shown to be toxic to the vegetation on which it was applied. In the same year Smith and Gouck (1944b) used DDT in various solvents to control the lone star tick and obtained reductions of up to 97 percent. It was reported one year later that nymphs and adults could be controlled for 68 days when 1 lb. of DDT + pine oil + water was applied to vegetation. DDT dusts were effective, but at least 3 lbs/A were required to suppress this pest (Smith and Gouck 1945).

McDuffie, et al. (1950) discusses some of the problems associated with lone star tick control through the use of chlorinated hydrocarbons. These workers found that effective control with sprays appeared to be dependent upon thorough coverage and penetration of tick-infested ground litter, either by the use of large volumes of liquid applied as coarse sprays or of smaller quantities applied as fine-mist sprays from close range. Drifted sprays were found to be unsatisfactory for lone star control. Aerial application of several chlorinated hydrocarbons was shown to be generally ineffective in controlling *A. americanum*. As much as 4 lbs/A of these materials were needed for effective control. A large-scale test by McDuffie, et al. (1950) showed that 4 lbs/A DDT gave a 76 percent reduction in lone stars within 1 week, 97 percent within 6 weeks, 99 percent up to 9 months and 70 percent for a period of 14 months. Results also indicated that large treated areas become infested more slowly than small experimental plots of an acre or less.

High mortality of ground and bush-feeding birds, and insectivorous reptiles were seen to occur for about one week after the aerial application of DDT (George and Stickel 1949). Aquatic organisms are often more sensitive than most terrestrial organisms to chlorinated hydrocarbons. Oxygen uptake in the gills is apparently impeded; death comes from suffocation, not – initially at least – from toxic effects on the central nervous system (Rudd 1964).

Chlorinated hydrocarbons such as DDT and lindane were recommended for use in tick control in the U.S. for several years (U. S. Dept. Agr. 1963, 1966). The need for better control measures have encouraged researchers to concentrate on integrated routes of pest control. The use of an effective short-lived pesticide in integrated control approaches is especially desirable.

While considering the ecological or environmental requirements of the lone star tick, *A. americanum* (L.) as demonstrated by Sactor et al. (1948), Lancaster and McMillan (1955), and Lancaster (1958), it was postulated that through an integrated control program involving vegetative alteration, chemical treatments, or a combination of these, lone star tick populations could be suppressed. Theoretically, vegetative alteration would produce a microhabitat which would be unfavorable for tick oviposition or hatch, molting, or normal longevity of the various stages. An effective acaricide could also supplement environmental alteration in achieving rapid suppression. Vegetative alteration in many instances could make the area unsuitable as animal habitat, and eventually the tick cycle would be broken if sufficient animal hosts were not available.

After three years of extensive laboratory tests involving most of the available insecticides, we selected Gordona as a tickicide to be used in integrated control studies. It was known that this material had a very low mammalian toxicity and a short half-life. Its effect on aquatic animal populations was thought to be insignificant when compared to other pesticides. A recent paper (Mount, et al. 1968) suggested that several organic phosphates are equally as effective as DDT for lone star tick control in wooded areas. However, most of the materials mentioned by these workers were eliminated in the early phases of our investigations because of their toxicity to fish or because of their persistent residues.

Several reports of integrated control of ticks involving vegetative alteration in conjunction with pesticidal application have appeared in the literature in recent years. McKiel, et al. (1967) used 3 formulations, involving 2 insecticides, lindane and DDT, and the herbicides 2,4-D and 2,4,5-T for effective control of the American dog tick, *Dermacentor variabilis* (Say), and brush along roadsides. Best results were obtained when these workers used 3.75 lb herbicide and 2 lb DDT in water at the rate of 50 gal/A.

In a review of the methods for control of tick paralysis of cattle in British Columbia, Wilkinson (1968) postulated that vegetative alteration would give satisfactory to high protection against tick paralysis in cattle, suggesting that effective tick control could be obtained by these methods.

The specific objective of the investigation reported herein was to evaluate the long-term effects of various mechanical, chemical or integrated measures on lone star tick populations.

Materials and Methods

Three demonstration areas were established July 15, 1967, with six 1-acre plots occurring in each area. The 3 areas were situated within a 1-mile radius in Cherokee County, Oklahoma, but differed slightly as to terrain and tick reinfestation pressure. Area 1 was open woodland, area 2 was creek bottom subject to overflow, and area 3 was woodland open to less than 15 percent sunlight penetration.

Each of the 3 test areas was divided into six 1-acre plots treated as follows: (1) mechanical clearing to remove approximately 75 percent overstory and all understory vegetation (2) mechanical clearing as in treatment no. 1 with the addition of an acaricide, (3) application of an acaricide to existing vegetation, (4) mechanical clearing as in treatment no. 1 with the addition of a herbicide, (5) application of a herbicide to existing vegetation, and (6) no treatment.

Where applicable, plots were cleared to simulate recreational areas by mechanical brush removal. No vegetation was removed from the uncleared plots.

The acaricide-treated plots were sprayed with Gardona (2-chlora-1 (2,4,5-trichlorophenyl) vinyl dimethyl phosphate) 75 percent WP formula at the rate of 1 lb of actual toxicant per acre applied in 22 gal of water.

Pretreatment counts were made in all experimental plots prior to acaricidal application, and reapplications to the acaricide-treated plots were made when tick populations demonstrated a marked increase.

In preliminary work during 1967, the plots were sprayed with 2-gal compressed-air hand sprayers. Control was satisfactory, but this technique was considered too slow and expensive for broad use. In 1968 and 1969, applications were made with a pick-up mounted high pressure power sprayer using a No. 7 nozzle subjected to a pressure of 300 psi.

During 1968 and 1969 acaricidal applications were made at approximately 6 weeks intervals, depending on the magnitude of tick numbers in the acaricide treated plots.

The herbicide plots were treated with 2,4,5-T OS (Dow Chemical Co.) at the recommended rate of 1 gal in 24 gal of diesel oil applied with 2-gal compressed-air sprayers. In the mechanically cleared plots, the herbicide was applied as a stump treatment as the area was cleared. The plots to be cleared by chemical means received the herbicide as a basal bark spray which was applied to the point of runoff. The amount of herbicide applied was dependent on the vegetative cover present.

Herbicidal applications were made during a period of hot, dry weather in the summer of 1967 and an unsatisfactory vegetative kill was obtained. The herbicide treatments were reapplied in May 1968 with satisfactory results.

Areas that received clearing and acaricide and clearing only were maintained by cutting back all regrowth at 6-week intervals during the growing season. After the initial treatment of herbicide and the retreatment in 1968, no further herbicide applications were made.

A heavy-duty sweep net, 15 in. diam. and a drag flag consisting of heavy-weight white muslin, 36 x 72 in., attached to a 3-ft dowel were used in estimating tick populations. The sweep net was employed in the usual sweeping method, while the drag flag was pulled behind the person taking the sample.

Each sample area consisted of an area 75 x 3 ft. Four samples were selected at random in each plot, and the average or mean number of ticks per sample was counted or estimated and recorded.

Population estimates were taken at 10- to 14-day intervals except when climatic conditions prohibited sampling. During periods of low tick activity, periodic samples were made to record their activity within the test areas.

Results and Discussion

The 1967 preliminary work covered only the larval season of the lone star tick. These data provided excellent background information for future tests.

Preliminary results (Table 9) indicated that Gardona, when applied to existing woodland or to simulated recreational areas as a wettable powder, gave excellent control of larval ticks for a period of more than a month. Clearing an area, or clearing with the addition of an herbicide also showed some promise as a means of tick reduction.

Follow-up studies were made during the summers of 1968 and 1969 and the treatments were summarized and ranked as to efficacy against adults as follows: (1) clearing plus Gardona; (2) Gardona; (3) mechanical clearing; (4) mechanical clearing plus 2,4,5-T OS; and (5) 2,4,5-T OS applied to existing vegetation. These data are presented in Table 10. Tables 11 and 12 summarize efficacy data on these various treatments during 1968 and 1969 against nymphs and larvae, respectively.

Excellent seasonal control averages were obtained when Gardona was used as a spray directly to existing vegetation — for tick control — or when it was applied to areas previously cleared by mechanical means.

Of particular interest and value were the data collected from areas receiving mechanical clearing. These data show that by year 2 after initial treatment, all stages of the lone star tick were reduced by at least 53 percent, and one might expect up to 75 percent control of adults and larvae (Tables 10, 11 and 12). Areas receiving clearing plus a herbicide were, in general, about as effective in reducing populations as clearing alone, but were more effective than the herbicide treatment.

Since these studies were conducted in an area known to be subjected to above normal reinfestation pressure, one can expect better results in established recreation areas (Hair, unpublished data).

The principal problem encountered in areas receiving only clearing as a potential means of tick reduction in recreation areas is that rapid regrowth of vegetation frequently occurs, especially in the spring. If this regrowth were allowed to remain, it could make conditions more favorable for host animals, and subsequently tick activity, than before any clearing had been done. In Oklahoma studies it was observed that wildlife activity tended to increase as regrowth of vegetation began in cleared plots. Deer preferred to browse on the tender 2nd growth and spent considerable time in the cleared plots that did not receive a herbicide. Small animal activity, especially that of the cotton rat, increased as more cover become available.

An integrated program consisting of one or more means of environmental alteration by mechanical and/or chemical treatment appears to be effective in area tick control. This type of control program is applicable to many of our recreational areas and will show an economic benefit if used.

Table 9. Larval counts and percent change from pretreatment in tick populations at simulated recreational areas following chemical and cultural-mechanical treatment. Counts represent average number of larval ticks/225 ft^2 of surface area.

Weeks Post-treatment	Clear + Rabon		245-T + Clear		Clear		Rabon		245-T		Control	
	No. larvae	% change	No. larvae	% change	No. larvae	% change	No. larvae	% change	No. larvae	% change	No. larvae	% change
0	316		411		269		705		101		540	
1	0	100[1]	124	70	109	60	0.2	100	21	80	547	+1[2]
2	8	97	53	87	152	45	10	99	65	35	64	88
3	66	79	3	92	107	60	16	98	96	4	513	5
4[3]	0	100	323	21	19	93	56	92	38	63	111	79

1 (−) = Decrease.
2 (+) = Increase.
3 Includes counts from only 2 replicates.

Table 10. Average seasonal reduction[1] of lone star tick adults in woodlots receiving various mechanical-chemical treatments during 1967, 1968, and 1969, Cherokee Co., Oklahoma.

Observations Made	Untreated	2,4,5-T	2,4,5-T + Clear	Clear	Clear + Gardona	Gardona
			Average seasonal reduction			
Year 1						
Post-treatment[2]	0	30	24	52	90	81
Year 2						
Post-treatment[3]	0	12	67	75	89	96

[1] All observations in a specific treatment for a particular year were averaged to yield this figure.
[2] 7 observations; Apr. 30 through Jul. 9, 1968.
[3] 6 observations; May 28 through Jul. 7, 1969.

Table 11. Average seasonal reduction[1] of lone star tick nymphs in woodlots during 1967, 1968 and 1969, Cherokee Co., Oklahoma.

Observations Made	Untreated	2,4,5-T	Clear	2,4,5-T + Clear	Clear + Gardona	Gardona
			Average seasonal reduction			
Year 1						
Post-treatment[2]	0	24	29	73	96	97
Year 2						
Post-treatment[3]	0	23	53	48	90	90

[1] All obsrevations in a specific treatment for a particular year were averaged to yield this figure.
[2] 7 observations; May 28 through Aug. 1, 1968.
[3] 8 observations; May 28 through Aug. 5, 1969.

Table 12. Average seasonal reduction[1] of lone star tick larvae in woodlots receiving various mechanical-chemical treatments during 1967, 1968 and 1969, Cherokee Co., Oklahoma.

Observations Made	Untreated	2,4,5-T	Clear	Clear + Herbicide	Gardona	Clear + Gardona
			Average seasonal reduction			
Year 1						
Post-treatment[2]	0	33	47	63	85	93
Year 2						
Post-treatment[3]	0	53	72	67	89	96

[1] All observations in a specific treatment for a particular year were averaged to yield this figure.
[2] 6 observations; July 23 through Sept. 5, 1968.
[3] 8 observations; July 7 through Aug. 27, 1969.

The results show that effective lone star tick control in recreational areas can be obtained by properly timing 2 or 3 applications of 1 lb of Gardona 75 percent WP/acre. In newly established or poorly maintained areas, more frequent treatment may be necessary.

This same program can be altered somewhat and applied to area control in pastures and other large outdoor areas.

One could generally expect that an application of Gardona at the beginning of the adult season, and an application at the beginning of the larval season (Figure 4) would maintain ticks at a tolerable level in most established resort areas.

Gardona Uses in Recreation Areas

The studies conducted by Clymer, et al. (1970) in 1967-68 and continued during 1969 are summarized in Tables 10, 11, and 12. These demonstrated the excellent tick control results one achieves when Gardona is used in recreation areas. The data presented indicate results obtained under the most adverse conditions, and even greater and longer-lasting control has been obtained with this material in well established recreation areas (Howell and Hair 1969).

Several factors make this pesticide the most desirable for use around recreation areas at this time: (1) it is approved by the USDA and Food and Drug Administration for use; (2) it is highly effective as a tickicide; (3) it is a short residual pesticide with very low mammalian toxicity; and (4) it is relatively safe for use in the immediate vicinity of water without worries of fish kill (see following discussion).

During the summer of 1969 an experimental woodlot area of 100 acres was treated with Gardona by aerial application in an effort to determine the feasibility of tick control with aerially applied Gardona dust. An equally important question to be answered by this study was whether or not Gardona could be applied to aquatic situations (around recreation areas) without producing apparent fish and invertebrate mortality.

The experimental area, one hundred acres in size, 5 acres wide and 20 acres long, was treated by fixed-winged aircraft (April 20, 1969) with 20 lbs of 5 percent Gardona dust per acre. The area selected had a history of being a "hot-spot" for ticks. The land was creek-bottom characterized by extensive underbrush and a dense overstory of vegetation. The stream, Greenleaf Creek, was approximately 70 ft wide, up to 5 ft deep and had a flow rate of approximately 2 ft./sec. at the time of application. Total surface water in the 100 A. treatment block was estimated at 6 A. The estimated amount of 5 percent Gardona applied to the stream surface was 127 lbs.

There were few invertebrates in the stream at the time of application, because of "dilution" resulting from recent spring rains. The stream supported a "good" fish population (at least 9 species). Invertebrate populations in the stream were determined before and after treatment through the use of *"Suber square-foot samplers"*.

Results from the aerial application of Gardona indicated that: (1) aquatic populations of invertebrates were not affected by the application; (2) terrestrial invertebrate forms, mainly wasps, flies and mayflies were susceptible (as expected) and a number of dead insects were noted floating on the surface of the stream; (3) no mortality of resident fish was noticed in any part of the stream, either in the treatment zone, below the treatment zone in the stream, or in the lake two miles downstream; and (4) excellent control of lone star ticks was achieved for 5 to 6 weeks. This probably resulted from lone star ticks continuing to egress from the forest floor after the Gardona had lost its effectiveness. For that reason, it is not feasible to use Gardona applied in this manner and expect tick control in heavily infested woodlots for an entire year. However, application of Gardona dust formulations by this method to well established resort areas would probably result in more extended control. Such results have been observed when ground application of Gardona to these two different area types have been compared.

The most significant information collected from this study was that even though large quantities of Gardona were applied to an aquatic situation, even to the water's surface, no mortality of fish within the stream, ground feeding birds, cold blooded vertebrates, or other animals was noted in follow-up observations. Such information is invaluable in today's efforts to avoid pollution of our environment. It should be remembered that, based on the information presented by Beynon and Wright (1969), harmful residues of this pesticide will not remain in the environment for more than several days.

Considering the efficacy data on Gardona against ticks, the safety of this material around man, his pets and for use around aquatic environments, we feel that this is the most appropriate material to recommend for use in an integrated approach to lone star tick control.

Steps for Recreation Area Tick Control

Based on Oklahoma field studies over the past 3 years, it is felt that the following points should be considered when planning a control program.

Brush Control — Unnecessary vegetation within parks, along their edges, or along the edges of nature trails should be eliminated. Though this may be done mechanically, several treatments may be required before resprouting is stopped. A number of effective herbicides are available commercially, and can be used. We have found Esteron, 2,4,5,-T OS (Dow Chemical Company) to be very effective for this purpose. Brush clearing serves several purposes: (a) it frequently discourages animal visitations and therefore results in fewer new ticks being introduced; (b) it removes protective convering in which lone star ticks may seek refuge while environmental conditions are unfavorable, or when they wish to deposit their eggs; and (c) since many ticks, especially adults and nymphs, depend on brush as an aid in finding host animals, brush removal (i.e. along trails) often pushes ticks back to other vegetation, and attachment to hosts does not occur since they do not brush against the plant on which the tick is waiting.

Grass clipping — In park maintenance, grasses should be kept under control by periodic mowings. Grasses over 6 in. tall offer considerable protection for ticks against sun and low moisture. There is also the added effect that mowing will dislodge and disperse masses of seed ticks. Once this is accomplished, most will succumb to desiccation. Tall grasses also encourage tick host animal activity since cover is provided.

Overstory vegetation — Removal of all unnecessary overstory vegetation allows greater sunlight penetration and results in higher soil surface temperatures within the park area. Lower humidity can probably be expected to occur and existing ticks will meet with a habitat generally unfavorable for existence. We recommend removal of overstory so that 50 - 80 percent of the park area soil surface is exposed when the sun is in any one position. Large "clumps" of trees or vegetation should be avoided when possible, since protection for ticks is often afforded in such areas.

Application of Gardona — Gardona should be applied at a minimum rate of 1 lb/A active as a spray when needed to control population buildups. As a precaution, it is avisable to make two applications of this material per year to insure against visitor exposure to tick attack. One application should be made as the tourist season begins in the spring and should not be made too far in advance of early-summer usage by visitors.

The second application of Gardona should be made near the end of June unless seed tick populations begin to appear prior to the last half of this month.

The need for more than 2 applications of Gardona will seldom occur in well established and well managed parks. Should heavy animal use of the area be noted, the need for additional applications can be anticipated.

Surveys — Flagging surveys as a tool to indicate the need for treatment within recreation areas are often worthless. The reason being that when a very sparce population exists, as often occurs in eastern Oklahoma's parks, flagging surveys fail to indicate a problem. A visitor to the same area, while leisurely passing the time, acts as an attractant. If the visitor tarries too long, the tick will eventually crawl to the source of the attractant and attack the host.

Gardona Insecticide 50 Wettable Power For Area Control

General Directions

Gardona Insecticide 50 is suitable for use in conventional hydraulic sprayers or low pressure knapsack sprayers with the minimum of agitation.

Use and Application Directions

Large Areas — The recommended rate is 2 lbs. of GARDONA Insecticide 50 in sufficient water to thoroughly cover one acre.

Small Areas — Thoroughly mix the proper amount of GARDONA Insecticide 50 in the amount of water as indicated in the dilution table. The resulting suspension (0.5 percent) should be applied thoroughly to areas such as: along roadsides and footpaths, to vegetation surrounding camping and picnic sites, to grassy and brushy areas nearby to recreational camping and picnic sites, to grassy and brushy areas nearby to recreational sites of all kinds and to areas where ticks may be present and annoying.

Dilution Table

Amount of Gardona Insecticide 50 Required for 0.5% Suspension in Water

1 Gal.	5 gal.	25 Gal.	50 Gal.
2 Oz.	½ Lb.	2 Lb.	4 Lb.

Precautions In Using

Caution! May be fatal if swallowed, inhaled or absorbed through skin. Avoid breathing spray mist. Do not get in eyes, on skin, or on clothing. If the material gets into the eyes, wash with plenty of water for 15 minutes; if irritation persists, see a physician. Wash thoroughly with soap and water after handling and before eating or smoking. Avoid contamination of feed and food-stuffs. Keep away from heat and open flame. Do not apply in dwellings. This product can be toxic to fish. Avoid applications to lakes, streams or ponds. Do not contaminate water by cleaning of equipment or disposal of wastes. Apply this product only as specified. Do not reuse empty container. Destroy it by perforating or crushing. Bury or discard in a safe place.

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