RELATIONSHIP OF LONE STAR TICKS [*AMBLYOMMA AMERICANUM* (LINNEAUS)] AND WHITE-TAILED DEER [*ODOCOILEUS VIRGINIANUS* (BODDAERT)] IN CHEROKEE COUNTY, OKLAHOMA

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PREFACE

The lone star tick [Amblyomma americanum (L.)] has been considered as one of the most important arthropod pests of man and animals in the southeastern United States. To better understand this important pest numerous studies have been conducted recently on its biology and ecology. This dissertation presents results of studies on the relationship of the tick to white-tailed deer in the Cookson Hills State Game Refuge in eastern Oklahoma.

This author wishes to express his appreciation to his major adviser, Dr. Jakie A. Hair, whose patience and guidance were invaluable throughout this study. Appreciation is also expressed to the other committee members, Dr. J. C. Lewis, Dr. T. H. Silker, and Dr. R. N. McNew for their assistance.

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Sincere appreciation is expressed to the Oklahoma State Department of Agriculture, and the ARS, Southern Region personnel who helped obtain and furnish funds for this project through Cooperative Agreement #12-14-100-10, 863 (33).

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CHAPTER I

INTRODUCTION

The lone star tick [Amblyomma americanum (L.)] has been considered as one of the most important pests of man and animals in the Ozark region and southeastern United States (Hooker, et al., 1912). It is not only an obnoxious pest due to its bite but is also a vector of many diseases such as Q-fever, Rocky Mountain spotted fever, tularemia, Bullis fever, and tick paralysis. Center for Disease Control (1974) indicated that there were 754 cases of Rocky Mountain spotted fever with 38 deaths in 1974. Practically all of these cases could be superimposed over the distribution area and activity period of the lone star tick.

In eastern Oklahoma, such high populations of this tick exist that it has been considered one of the factors deterring the economic development of the area. Tourism is fast becoming the chief industry of this area because of the many man-made reservoirs, an abundance of wildlife, and rich Indian and Western heritage. However, the full potential probably will not be realized until tick populations can be reduced to a tolerable level. In addition to its annoyance and transmission of diseases to man, the lone star tick poses a problem to both wildlife and domestic animal management in the area. Bolte et al. (1970) reported that up to 57% of all newborn deer fawns [Odocoileus virginianus (Boddaert)] in eastern Oklahoma were lost and that deaths were tick associated. Under laboratory conditions, Hoch (1973) determined that young fawns subjected to 150-540 adult lone star ticks per week for ca 4 weeks would die. Natural infestations many times the above levels have been commonly observed. Considerable losses are incurred by the cattle industry each year as a result of parasitism and pathogenicity of the lone star tick. Prior to the screw-worm eradication program, this tick was a predisposing cause of screw-worm attack.

In developing control methods for this tick it is important to know as much as possible about it. A considerable amount of information now exists on certain aspects of the biology and ecology of the lone star tick in the Ozark region (Lancaster, 1955, 1957, 1973; Lancaster & McMillan, 1955; Tugwell & Lancaster, 1963; Clymer, et al., 1970a; Hair & Howell, 1970; Semtner et al., 1971a, b; Hoch, et al., 1971; Hair, et al., 1972; Wilson, et al., 1972; Semtner & Hair 1973a, b; Semtner, et al. 1973; Robertson, et al., 1975a, b). Literature revealed very little information on the tick-host relationship except in the area of animal host surveys (Tugwell & Lancaster, 1962; Drummond, 1967; Clymer et al., 1970b) and tick infestation effects (Bolte, et al., 1970; Barker, 1973; Hoch, 1973).

To better understand certain aspects of the tick-host relationship, studies were conducted to determine seasonal abundance of each tick stage on white-tailed deer; to relate white-tailed deer utilization of different habitats to tick populations; and to ascertain behavior and survival of the lone star tick replete female and larvae in different habitats as related to potential white-tailed deer exposure.

CHAPTER II

SEASONAL ABUNDANCE OF LONE STAR TICKS ON WHITE-TAILED DEER

The lone star tick [Amblyomma americanum (L.)] is a 3-host tick that attains its blood meals from one of a number of warm-blooded animals (Hooker, et al., 1912; Bishopp & Trembly, 1945; Brennan, 1945a, b; Tugwell & Lancaster, 1962; Diamant & Strickland, 1965; Clymer, et al., 1970b; Cooney & Burgdorfer, 1974). Frequently the larger hosts support all 3 stages of the tick (Bequaert, 1946; Clymer, et al., 1970b). Several authors report white-tailed deer [Odocoileus virginanus (Boddaert)] as the principal wild host of the lone star tick (Bishopp & Trembly, 1945; Brennan 1945a; Clymer, et al. 1970b; Cooney & Burgdorfer, 1974).

In eastern Oklahoma, the Cookson Hills State Game Refuge afforded an excellent opportunity to conduct studies in the area of tick-white-tailed deer relationships. The refuge was comprised of ca 5665.8 ha., designated primarily for propagation of white-tailed deer, had limited public access, and since no cattle were present deer were the most consequential host. This area of our ecological investigations was initiated to determine seasonal abundance of the different developmental stages of the lone star tick on white-tailed deer.

Method and Materials

During 1973 and 1974, deer were trapped every 2 weeks year-round utilizing live traps furnished by the Oklahoma Department of Wildlife Conservation. Deer were baited to traps with a sweet feed, Walker's Pride[R] Thoroughbred Allgrain. After a deer was trapped, a portable squeeze chute was placed in front of the trap and when the door was raised the deer was moved into the chute and restrained. The deer's head was drawn through a small side door of the chute allowing close examination of the ears for ticks. The numbers of ticks on the ear were used as an index of the level of tick infestation on the entire animal. Total numbers and the repletes of each tick stage were noted. For later identification, deer were tattooed in the ear with a S-T2[R] tattoo set (Stone Manufacturing and Supply Company, Kansas City, Missouri) and released. Approximately 10 deer were trapped each month and the average number of each tick stage per deer was used as the mean level of infestation for that particular trapping date.

Results and Discussion

In 1973, trapping was not initiated soon enough to determine earliest feeding activity of the female tick; however, significant activity was occurring in early May (FIG. 1) when trapping first begun. Infestation levels of flat females rose rapidly to a peak average of 167 $\pm$ 57.73/deer in early June and declines gradually throughout the summer and early fall until none were observed in early October. The number of replete females peaked sharply at an average of 46 $\pm$ 14.93/deer in late June and declined until none were observed at the end of August (FIG. 1). In 1974, the earliest feeding activity began in mid-February and rose to an average level of 90 $\pm$ 31.18/deer in early June and then

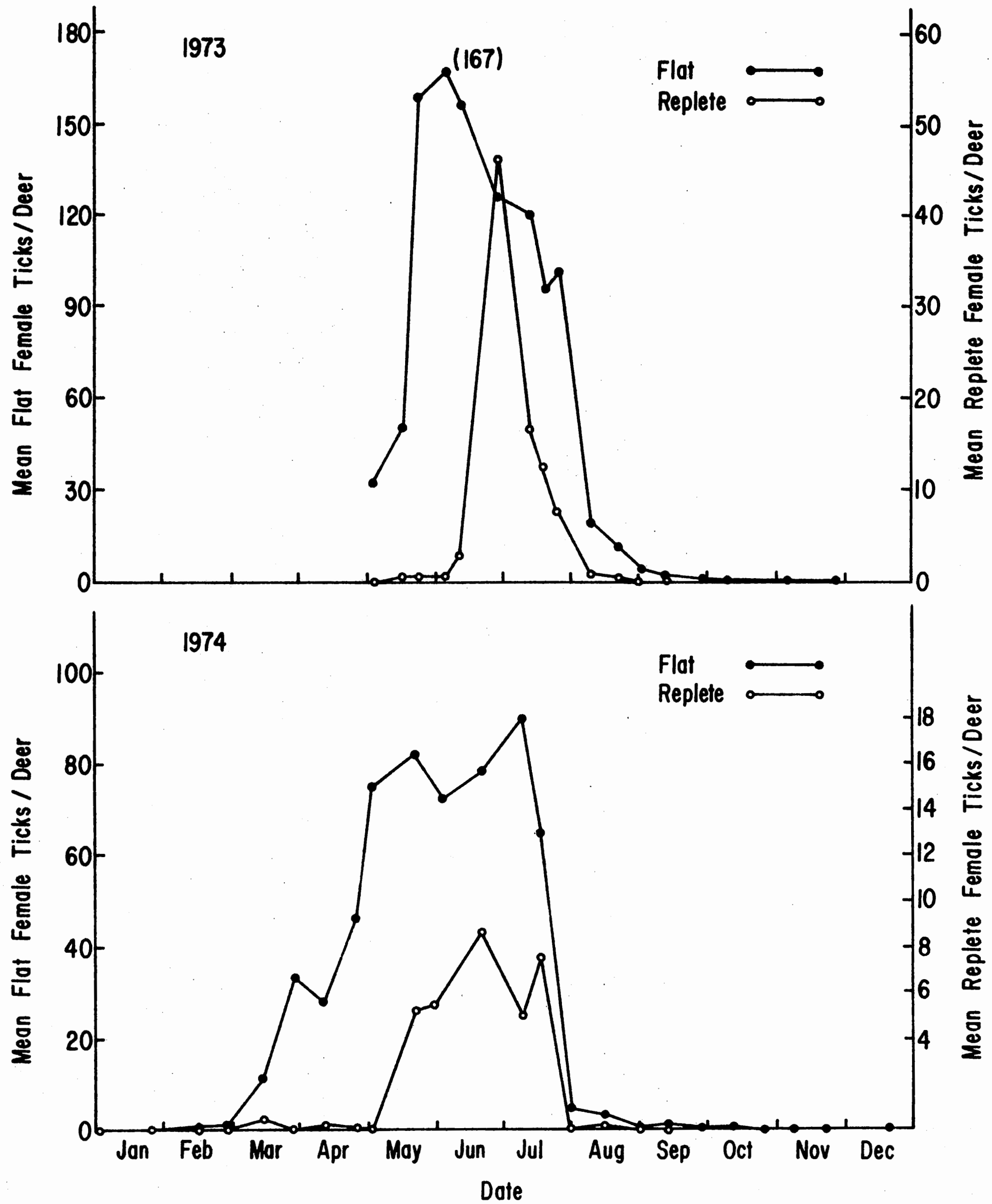

FIG. 1. Mean number of flat and replete female ticks on the ears of deer in the Cookson Hills State Game Refuge in eastern Oklahoma, 1973 & 1974.

declined until none were observed in late October (FIG. 1). Replete females peaked at 9 $\pm$ 10.44/deer in late June and none were observed by the end of August (FIG. 1). This seasonal abundance pattern of adult lone star ticks was quite similar to what Cooney & Burgdorfer (1974) reported on 4 different hosts in Tennessee and Drummond (1967) recorded on cattle in Texas.

The level of infestation of flat adult ticks for 1973 was ca 2X greater than that of 1974 (FIG. 4). This difference of infestation levels may be a consequence of the differing available moisture for each year. Several authors (MacLeod, 1935; Brennan, 1945b; Lees & Milne, 1951; Semtner, et al., 1971b; McEnroe & McEnroe, 1973) have studies the behavior of ticks in response to available moisture. Generally, these authors indicated if there was no moisture deficit in the body of the tick, it would migrate up the vegetation. If there was a moisture deficit in the tick, it would return to or remain in the vegetative mat with its higher humidities and reabsorb moisture if humidities were above its critical equilibrium humidity (CEH) (Lees, 1946, 1947, 1948; Browning, 1954; Hafez, et al., 1970; Sauer & Hair, 1971). In 1974, available moisture in the form of humidity and precipitation was considerably less than in 1973 (FIG. 2, TABLE 1). The lone star tick would have had to spend more time on the ground replenishing body water in 1974 than in 1973; therefore, reducing its exposure to deer with resultant lower tick infestation levels. Another possible factor in the explanation of the difference of infestation levels for the 2 years was ca 20% reduction of deer from 1972 to 1973 (Joe Fletcher, personal communication).[1]

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[1]Cookson Hills State Game Refuge Manager.

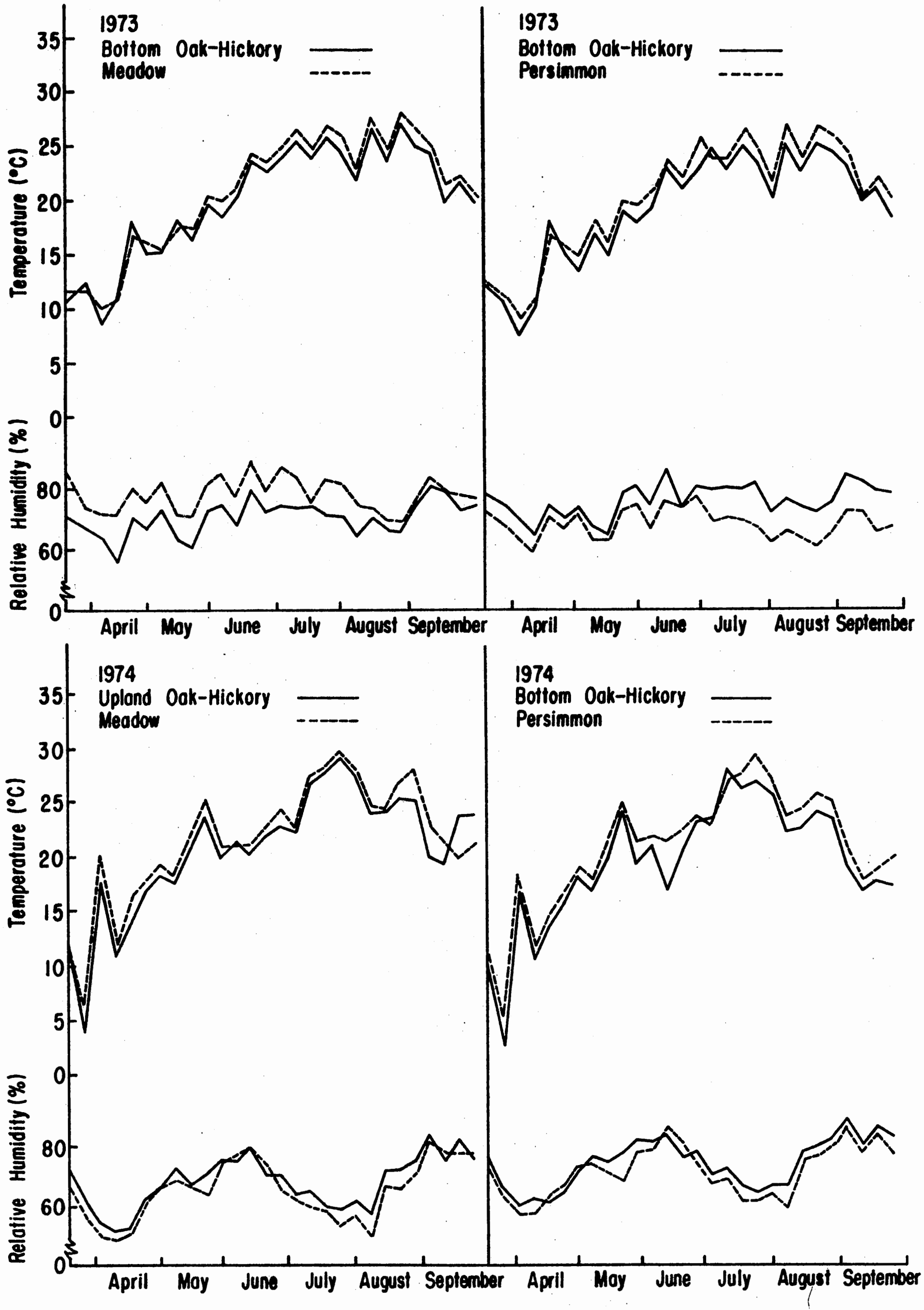

FIG. 2. Temperature and relative humidity in 4 different habitats in the Cookson Hills State Game Refuge in eastern Oklahoma, 1973 & 1974.

TABLE 1. Monthly precipitation in eastern Oklahoma[a] from April through September, 1973 & 1974.

Month	Precipitation (mm)	Departure from Normal (mm)
1973		
April	193.36	+ 65.09
May	155.13	- 1.84
June	242.74	+119.42
July	69.05	- 17.18
August	98.29	+ 15.48
September	239.24	+136.62
1974		
April	130.02	+ 1.75
May	60.20	- 96.77
June	199.25	+ 15.93
July	5.84	- 80.39
August	181.99	+ 99.18
September	270.06	+167.44

[a]Means of climatological data for Sallisaw, Tenkiller Dam, Stilwell and Tahlequah weather stations. U.S. Dept. of Commerce 1974, Climatological Data, Oklahoma. Superintendent of Documents, Government Printing Office, Washington, D.C.

With fewer deer available as hosts, fewer ticks would be produced to infest deer during 1974.

FIG. 1, also, illustrates a repression of repletion for both years, in that even though large numbers of flat females were feeding early in the summer, repletion did not begin until May and at a similar time for both years. This behavior appeared to be a photoperiod response that resulted in a more narrow replete drop-off period and subsequent larval hatch period.

Male lone star ticks were found on deer during all months of this study. This was assumed to be due to the failure of males to drop from the host and to the long survival time of males on the host. In 1973 and 1974, highest average infestation levels were 1055 $\pm$ 278,21/deer early in July and 655 $\pm$ 141.01/deer in late June (FIG. 3). The difference of infestation levels for the 2 years was, again, attributed to less available moisture and fewer hosts in 1974 as compared to 1973. The mean number of males peaked at a level considerably higher than the females. This was probably a result of the cumulative effect of the male's ability to mate and feed several times (Hooker, et al., 1912; Sactor, et al., 1948; Balashov, 1956; Gladney & Drummond, 1970) and remain on the deer for much longer periods of time than the female.

The period of nymphal infestation on deer was longer than any other stage and occurred from March to October with no definite peak in activity (FIG. 4). This was due to the free-living nymphal activity patterns observed by Semtner & Hair (1973b). They indicated nymphal activity from March to October with no general peak such as was observed among adult ticks. They noted that peak nymphal activity varied as much as a month from one habitat to another presenting a continuous

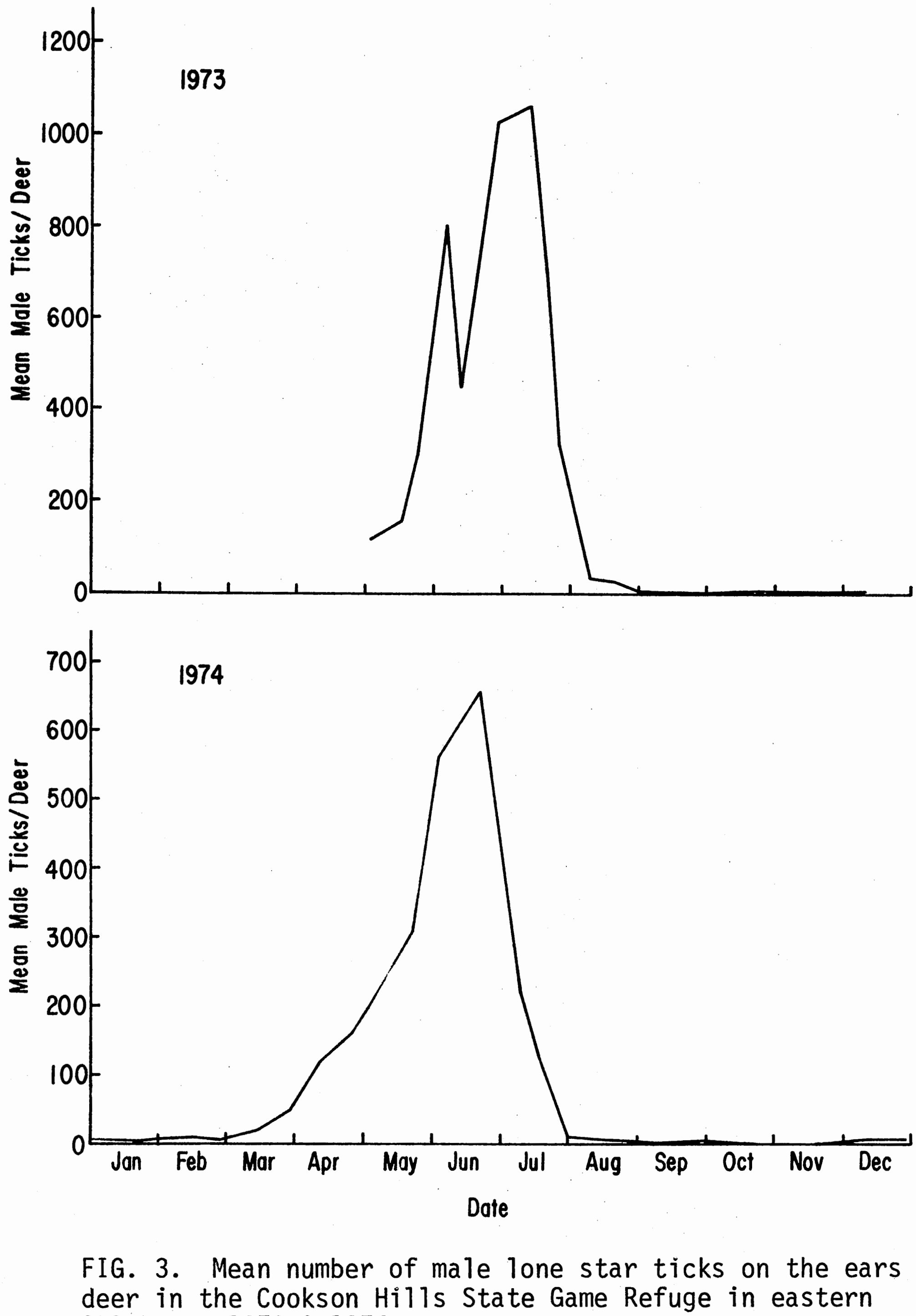

FIG. 3. Mean number of male lone star ticks on the ears of deer in the Cookson Hills State Game Refuge in eastern Oklahoma, 1973 & 1974.

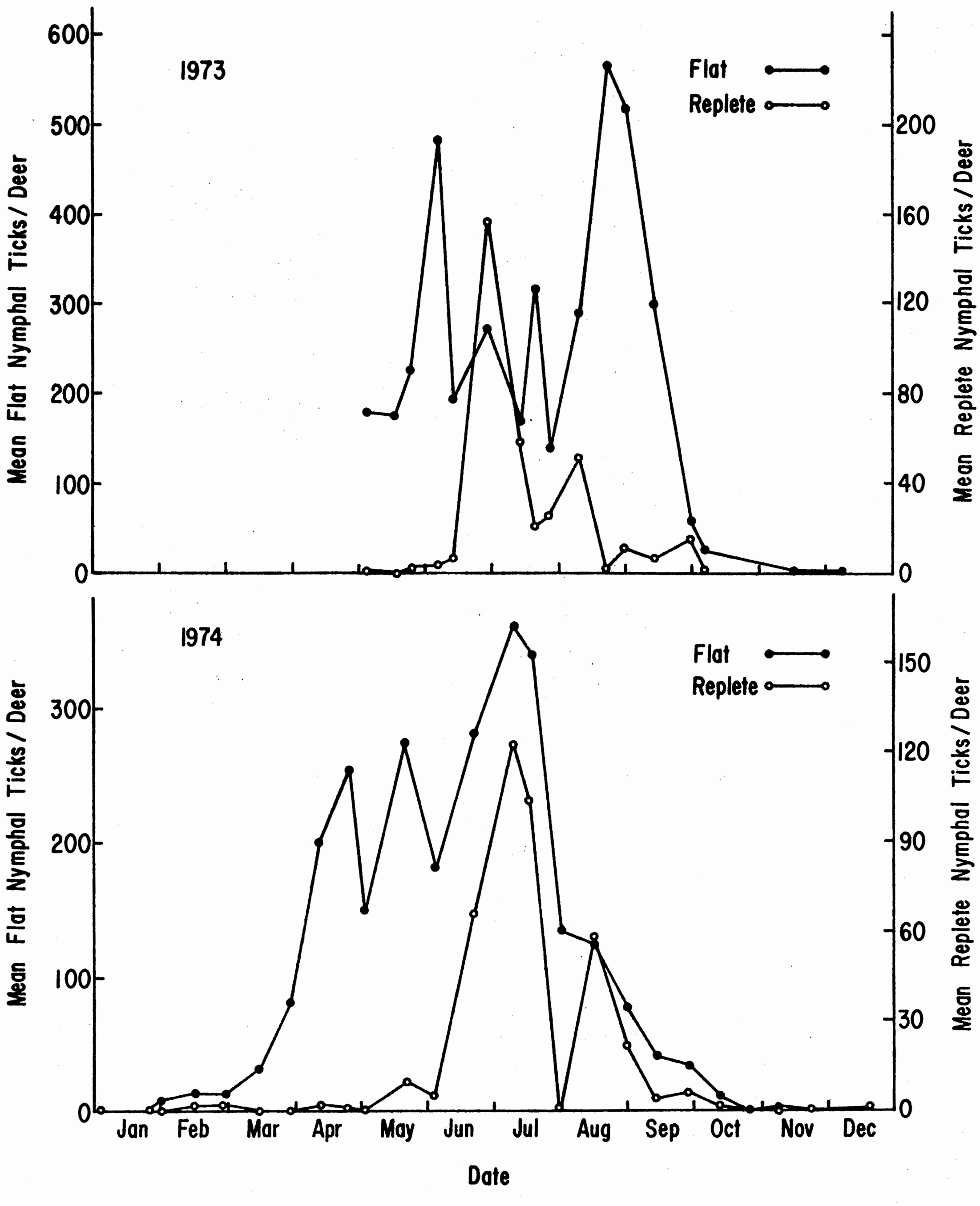

FIG. 4. Mean number of flat and replete nymphal lone star ticks on the ears of deer in Cookson Hills State Game Refuge in eastern Oklahoma, 1973 & 1974.

exposure to the wide ranging white-tailed deer. In Tennessee, Cooney & Burdorfer (1974) noted a nymphal peak in August but with significant activity from May through September. In 1973, the numbers of replete nymphs on deer peaked at an average of 390 $\pm$ 96.80/deer in late June and in 1974 they peaked at an average of 270 $\pm$ 67.09/deer in early July (FIG. 4). Infestation levels were considerably different over the 2 seasons with an average high of 565 in 1973 in contrast to an average high of 360 in 1974, again, this is attributed to less available moisture and the fewer hosts that existed in 1974.

FIG. 4 reveals a repression of repletion in nymphs similar to that which occurred with the females. Again, this behavior appeared to be controlled by photoperiod because significant repletion did not begin until June of each year. With peak repletion occurring late in June and early July and then the addition of ca 30 days molting time (Semtner, et al., 1973), one can see that the peak in emergence of newly molted adults would not occur until August. Semtner, et al. (1973), reported that engorged nymphs molting after 15 July would not become active as adults during the same season, but would remain in diapause until spring of the next year. This behavior of repressed repletion until June appears to have survival value in that the newly-emerged adult would not have to contend with the hot dry conditions of the summer and therefore increases its chance for survival to become active the next year when environmental conditions are more favorable.

In 1973 (FIG. 4) a second peak in the numbers of flat nymphs occurred but there was no subsequent peak of repletes. This late season repression of repletion may have been controlled by photoperiod which prevented large numbers of replete nymphs from being produced at a time when they would be unable to molt to adults before cooler weather (Semtner, et al., 1973). This late peak was not observed in 1974 and was possibly due to low populations of larvae in July and August.

Larvae first appeared on deer in late June of both years. Infestations peaked at an average of 3175 ± 624.15/deer in late July of 1973 and at an average of 700 ± 104.15/deer early in August, 1974 (FIG. 5). Larvae occurred at an average of 2175 ± 431.81/deer late in July and at an average of 315 ± 75.76/deer early in August, 1973 and 1974, respectively. These data agreed with peak activity of free-living larvae observed by Semtner & Hair (1973b). Again, considerable differences of infestation levels on deer occurred over the 2 seasons. Peak oviposition of replete female lone star ticks occurred in June and July as indicated by previous data of seasonal abundance of replete females on deer. During the 1974 season, an extremely dry and hot period occurred from mid-June until mid-August (FIG. 2, TABLE 1) and had a very detrimental effect on the larval production. This resulted in low levels of infestation of deer.

In 1974 (FIG. 5) a second flat larval peak occurred in late September but no significant increase in replete larvae was noted. This second peak in flat larvae likely occurred as a result of very favorable weather in late August and early September (FIG. 2, TABLE 1), but a photoperiod response prevented repletion at a time that would have been unfavorable since an engorged larvae could not likely molt before cooler weather and could not overwinter.

Summary

With live trapping of white-tailed deer, the peak of infestation

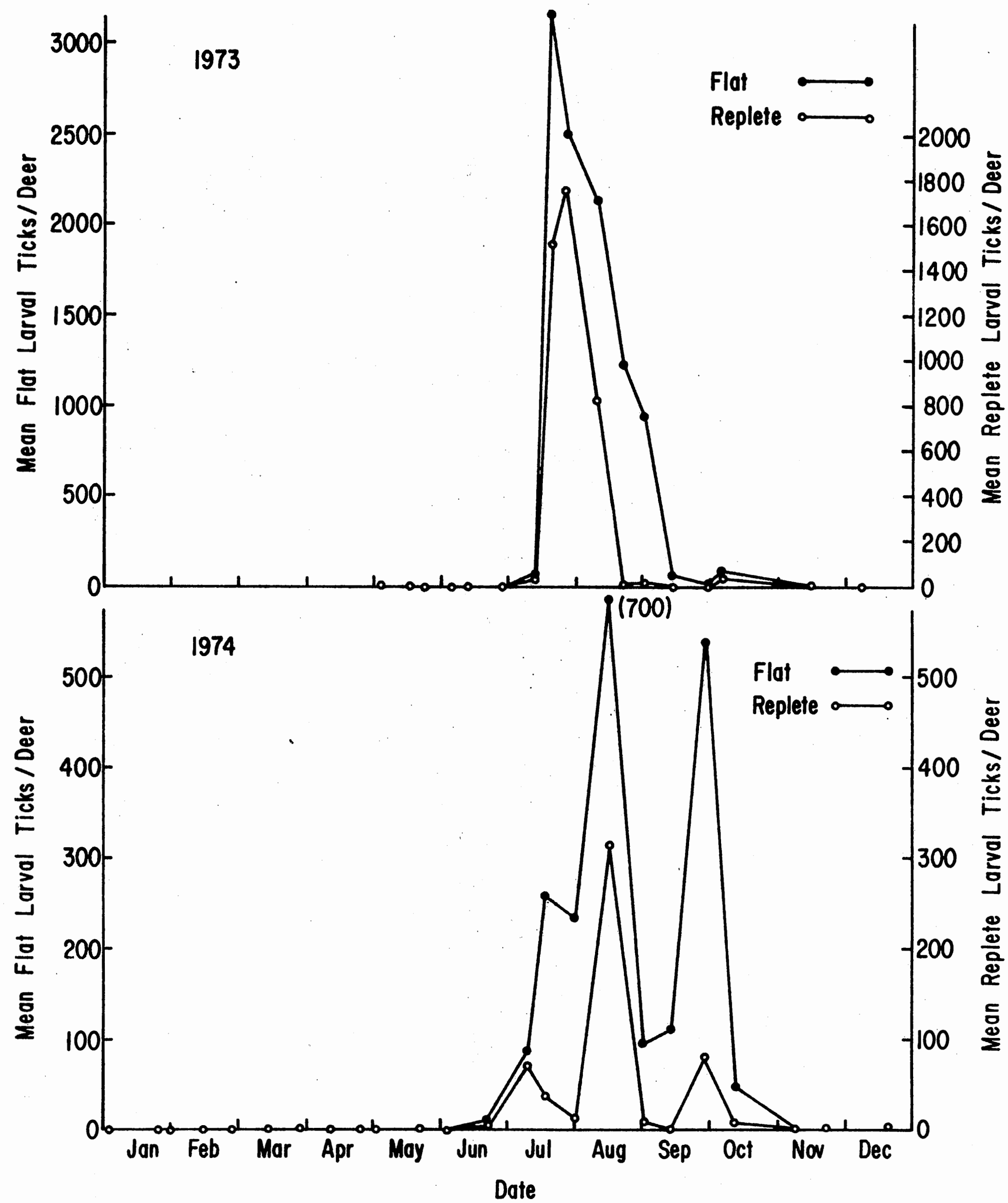

FIG. 5. Mean number of flat and replete larval lone star ticks on ears of deer in Cookson Hills State Game Refuge in eastern Oklahoma, 1973 & 1974.

of each tick stage was determined to correspond well with the peak activity patterns of the free-living stage. Peak infestation of adult ticks on deer occurred in late May, June and early July. Significant nymphal tick infestation was observed from April to October. Peak larval tick infestation occurred in late July and August. The dynamics of the infestation levels were affected by climatic conditions and deer numbers.

Repression of repletion of the adult and nymphal stage, apparently a response to photoperiod, has survival value in that the subsequent stage after molt did not become an active host-seeker at a time that was unfavorable for its survival.

CHAPTER III

WHITE-TAILED DEER UTILIZATION OF DIFFERENT HABITATS AND ITS INFLUENCE ON LONE STAR TICK POPULATIONS

The lone star tick [*Amblyomma americanum* (L.)] has been considered by many to favor certain vegetative types (Brennan, 1945b; Lancaster, 1957; Sonenshine, et al., 1966; Semtner, et al., 1971a, 1971b; Semtner & Hair 1973a, b; Semtner, et al., 1973). The environmental conditions created by these different habitats were the principal concern of the above researchers. Semtner, et al. (1971b) reported that the lone star tick survived much longer in a bottom oak-hickory habitat than it did in a meadow, upland oak-hickory, or persimmon habitat. It was noted that the bottom oak-hickory habitat typically had higher humidities and lower temperatures than did the other 3 habitats (Semtner, et al., 1971b) and these environmental factors accounted for the greater suitability of this type of area as tick habitat. Such past observations suggested that this particular habitat would support the greatest numbers of ticks. It has been noted that this is not always true in the Cookson Hills State Game Refuge, Cherokee Co. Oklahoma (Semtner, et al., 1971a). In this area the winged elm-sassafras-persimmon habitat has supported the largest numbers of ticks, but their survival time has not been maximum in this habitat. This observation suggested that factors other than climatic influenced tick populations of different habitats. Winged elm, sassafras, and persimmon typically represent the ecotone or "edge" area habitat in eastern Oklahoma. This is the zone that exists between open meadow and tree-lined areas and in which the heaviest desirable cover and the greatest available food frequently exists for white-tailed deer. Severinghaus & Cheatum (1956) reported that the white-tailed deer has always found its best environment and produced its greatest populations where "edge" was most abundant. It appears that the lone star tick not only depends on the host for its food and mating opportunity but, also for spatial distribution.

Host utilization of different habitats has considerable influence on tick numbers in specific habitats. MacLeod (1934) and Milne (1947) studies the host relationships of the sheep tick [*Ixodes ricinus* (L.)] in Britain and found that tick abundance was related to the presence of sheep. MacLeod found that removal of the primary host (sheep) from an area reduced the populations of ticks in the area and that the denser the sheep stocking rate the greater the tick population. In Cherokee Co., Oklahoma, white-tailed deer have been shown to be the primary host of the lone star tick (Clymer, et al., 1970b). Many other animals serve as hosts for the lone star tick in the Ozark region (Tugwell, Lancaster, 1962; Clymer, et al., 1970b), but, excepting cattle, their numbers and the tick infestation levels occurring on these hosts are not sufficiently high as to maintain tick populations that have been observed in Cherokee Co. White-tailed deer serve as hosts for all 3 stages of the lone star tick and would appear to have the greatest impact of any host on the abundance of the tick where cattle are not abundantly present.

It was the purpose of this study to investigate one area of tick-host relationships by determining the effect habitat utilization by white-tailed deer had on the lone star tick population in different habitats.

Methods and Materials

Statistical design was a randomized complete-block of 5 replicate plots of 3 different habitat types (bottom oak-hickory, upland oak-hickory, and meadow) which were classified by the Phillips (1959) point-quarter system in different areas of the refuge. The bottom oak-hickory habitat was characterized by white oak (*Quercus alba*)[1], black oak (*Q. velutina*), bitternut hickory (*Carya tomentosa*) and scaly-bark hickory (*C. ovata*) as overstory and had little or no undergrowth and a dense leaf litter. Post oak (*Q. stellata*), black oak (*Q. velutina*), blackjack oak (*Q. marilandica*) and black hickory (*C. texana*) comprised the overstory of the upland oak-hickory habitat with buck brush (*Symphoricarpos orbiculatus*) and Virgnina wildrye (*Elymus virginicus*) comprising the majority of the undergrowth. The meadow contained mainly broomsedge (*Andropogon virginicus*) and bermuda grass (*Cynodon dactlon*). Because of differences in deer distribution in the different areas of the refuge, an attempt was made to select areas in which all 3 habitats occurred in close proximity of each other. This would allow free-choice deer access to contiguous habitats. White-tailed deer utilization of the different habitats was estimated by pellet-group counts (Bennet, et al., 1940; Hosely, 1956) made in each habitat twice a month. Plots .04 ha. in size (Bennett, et al., 1940) were marked

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[1]Botanical nomenclature will follow that of U. T. Waterfall, 1970. *Keys to the Flora of Oklahoma*. Okla. State Univ., Stillwater. 243 pp.

off in each habitat with the corners identified by surveyor's flags. Initially all pellet-groups were moved from each .04 ha. plot but thereafter marked with Day-Glo pigment[R] when counts were being made to prevent later recount.

Carbon dioxide traps were used to monitor the tick population in each habitat once every 2 weeks (Wilson, et al., 1972). Trapping was made simultaneously (or as near as possible) in each of the habitats prior to making the pellet-group counts to allow for minimum disturbance of the tick population. Numbers of each stage of the lone star tick trapping were recorded.

Temperatures and humidity were measured in each habitat type continuously throughout the study period with Belfort Hygrothermographs[R] placed within standard weather station shelters. These data were considered as environmental factors possibly affecting the tick population.

Analysis of variance of the above data was conducted to determine if a relationship existed between deer utilization and tick numbers of certain habitats. That is, what role does the white-tailed deer play in determining tick populations in different habitats?

Results and Discussion

Habitat Utilization. Statistical analysis of habitat utilization data from mean pellet groups for 1973 showed little difference ($P<10$, 3df) in use occurred among habitats. Biologically there appeared to be differences in the use pattern because the meadow received more use in the early spring and the upland oak-hickory habitat received more use through the summer (FIG. 6, 7, 8, 10). In 1974, even with increased sampling, such variable data occurred that no statistically significant

($P<.10$, 6df) relationship existed between habitat and deer utilization, but again, there appeared to be more use of the meadow habitat in the early spring with upland oak-hickory habitat being used more through the summer. This pattern of use is possibly explained by management techniques on the refuge. In the fall the meadows were overseeded with legumes such as alfalfa and clover (Joe Fletcher, personal communication). These plants provided excellent forage for white-tailed deer (Dalke, 1941) during late winter and early spring when succulent growth was limited. As the meadow matured to the grass state, deer-use changed to a habitat with more available food such as an ecotone habitat or, in this case, upland oak-hickory habitat. Although the ecotone with the presence of a large variety of food plants (Bartlett, 1938; Severinghaus & Cheatum, 1956) was recognized as the most heavily used habitat in any area sampled in the Cookson Hills State Game Refuge, it was not extensive enough in area to allow reliable measurement of deer-use. Semtner (1971a) found highest populations of ticks in vegetative types such as the winged elm, persimmon, and sassafras which were a part of the ecotone. Except for the ecotone, the upland oak-hickory habitat received the greatest deer-use. It provided a larger variety of food plants than either the meadow habitat (mostly occupied by grasses) or the bottom oak-hickory habitat (practically devoid of any food plants within reach of the deer). Deer-use was not measured in the fall after tick season because of leaf-fall, and the bottom oak-hickory may have received considerably more use than earlier in the year because of the presence of mast producing trees such as white oak.

Tick Abundance in Different Habitats in Relation to Deer Use. The upland oak-hickory and the bottom oak-hickory habitats supported the largest populations of all tick developmental stages and the meadow habitat supported the lowest populations (FIG. 6-10). Several other authors have reported that lone star tick populations were higher in wooded and brushy areas as compared to open areas (Brennan, 1945b; Lancaster, 1957; Sonenshine, et al., 1966; Semtner, et al., 1971a; Semtner & Hair, 1973b). Even though the meadow received considerable use during both years it was not reflected in the tick numbers trapped there. High numbers of replete female ticks were found on deer when the meadow habitat was receiving its highest use (FIG. 6, 7) and this should be reflected in trapping of large numbers of larvae in the meadow habitat in July, August, and September. Apparently the high temperatures and low humidities that the replete female was subjected to in the meadow (FIG. 2) either resulted in her death, no oviposition, low egg hatch or low survival of larvae, because few or no larvae were trapped in the meadow during the mid-to late summer period (FIG. 6, 7). Robertson (1974) reported that larvae had significantly shorter life spans under typical meadow conditions during the summer.

The upland oak-hickory habitat consistently received higher deer-use than the bottom oak-hickory habitat (FIG. 6, 7) and therefore, more replete female ticks probably dropped off in the upland oak-hickory than in the bottom oak-hickory. In 1973, a reflection of this use-pattern can be seen in the trapping of larval ticks. Considerably more larvae were trapped in the upland oak-hickory than in the bottom oak-hickory this year. In 1974, with a deer-use pattern similar to 1973, no difference can be seen in the larval trapping data of the 2 habitats. This would appear to discredit the idea that deer-use of a particular favorable habitat would determine the tick population of that habitat.

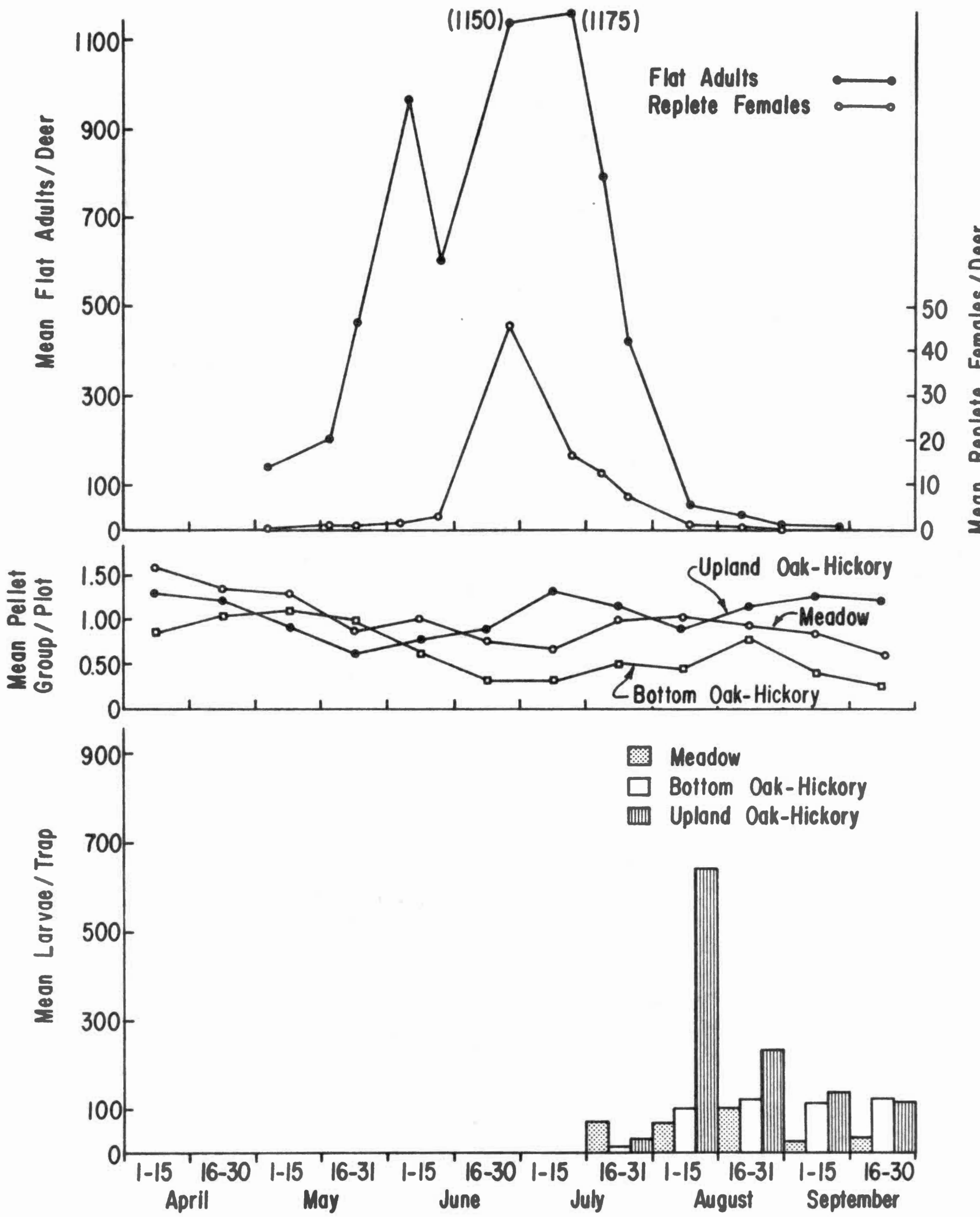

FIG. 6. Seasonal abundance of adults and replete females on deer in relation to utilization (avg. pellet group/plot) and larval trapping in 3 different habitats, 1973.

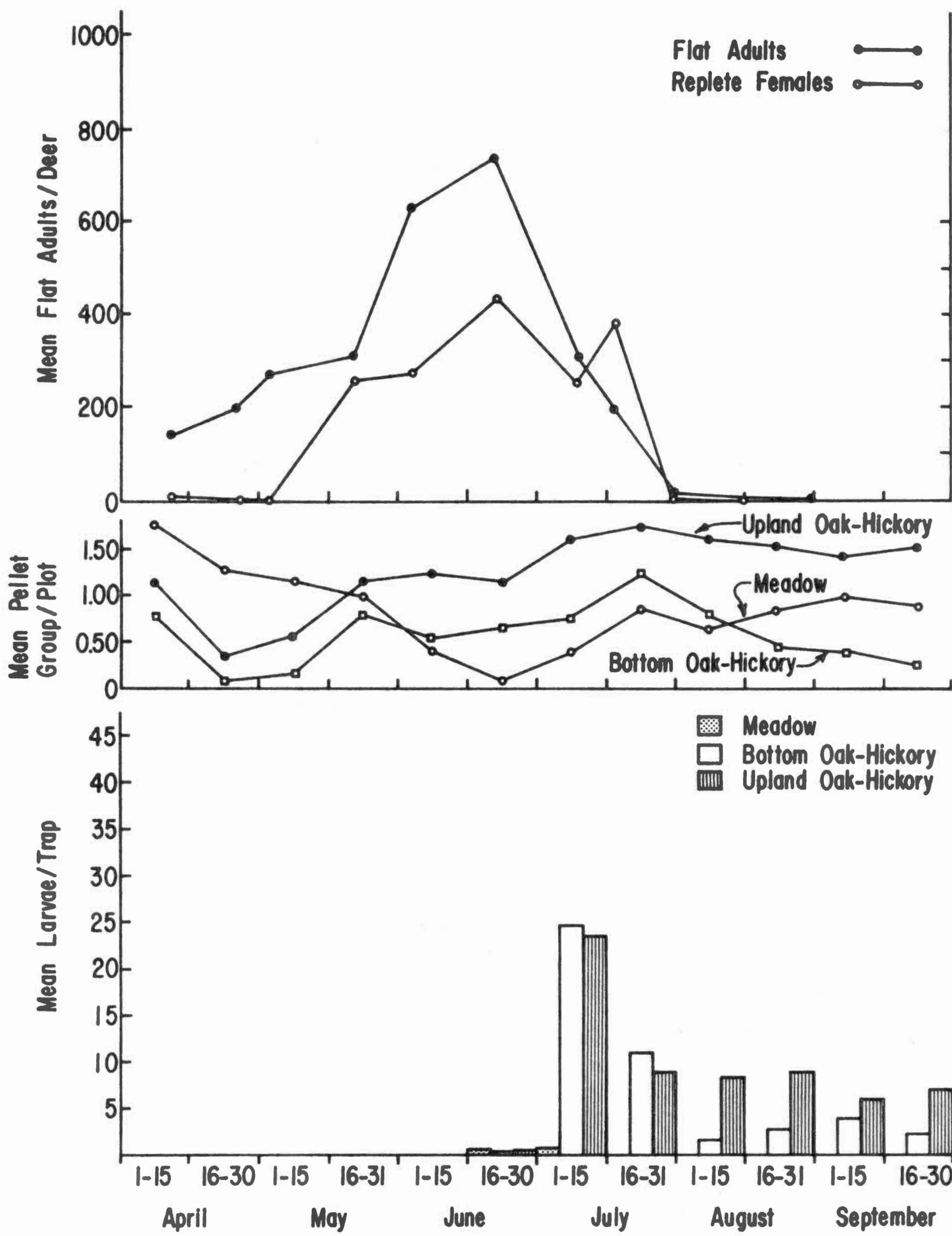

FIG. 7. Seasonal abundance of adults and replete females on deer in relation to utilization (avg. pellet group/plot) and larval trapping in 3 habitats, 1974.

However, if one looks at the numbers of larvae trapped he will see an average high of 640 larvae per trap in 1973 in contrast to an average high of 25 larvae per trap in 1974. It was also noted that there was no real difference in the number of larvae trapped in the bottom oak-hickory over the 2 years. These data show that some factor or factors reduced the population of ticks in the upland oak-hickory even though it had high deer-use. Climatically, 1974 was a very atypical year for eastern Oklahoma in that conditions were dryer and warmer than normal (FIG. 2, TABLE 1). These unusual conditions apparently affected the upland oak-hickory in such a way as to make it less suitable for tick survival than would ordinarily be the case under more normal conditions such as those of 1973. The bottom oak-hickory was exposed to the same conditions. It is a cooler, more moist environment so apparently it did not change enough to become unfavorable for larval tick survival and therefore no real change in tick population occurred in this habitat.

The reduction of host numbers may also have affected the tick populations of the various habitats over the 2 year study period. In 1973, fewer deer were available to serve as host; therefore, total tick production was reduced and was reflected in lower tick populations in 1974.

Semtner & Hair (1973b) reported significant nymphal activity from April through October in various habitats. This was also reflected in this study where levels of infestation on deer remained considerable from April through September (FIG. 8). With the pattern of habitat utilization during nymphal activity, the meadow and upland oak-hickory habitats should have had considerable exposure to drop-off of replete nymphs, but again, the meadow did not indicate this in the trapping

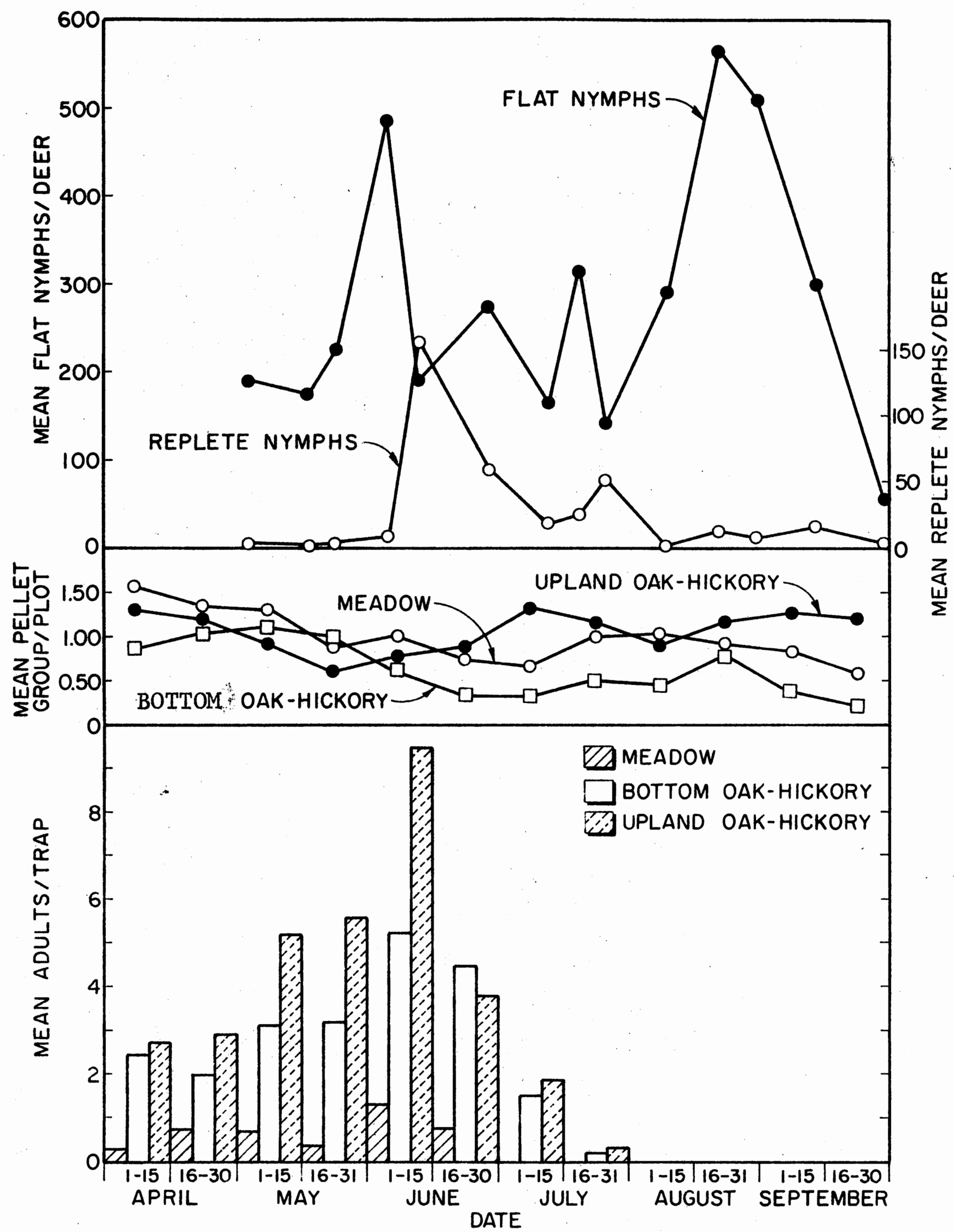

FIG. 8. Seasonal abundance of flat and replete nymphs on deer in relation to utilization (avg. pellet group/plot), 1973, and adult trapping in 3 habitats, 1974.

of adults the following year (FIG. 8). The more harsh conditions of the meadow apparently are more detrimental to the survival of the nymphal tick during molt, or to the newly molted adult. Those replete nymphs dropped into the upland oak-hickory had better survival as noted by trapping of adults in this habitat the following year. The bottom oak-hickory received considerably less deer-use than the upland oak-hickory. However, in adult trapping in 1974 very little difference can be seen between these 2 habitats (FIG. 8). Again, one must compare adults trapped in a more normal year like 1973 (FIG. 9) with that of 1974. Not much change can be seen over the 2 years in the adult trapping results in the bottom oak-hickory, whereas a considerable reduction occurred in adults trapped in the upland oak-hickory. Similar reasons as those stated for larval trapping are considered valid for the results seen in adult trapping (i.e. the climatic conditions that existed in 1974 were extreme enough to make the upland oak-hickory habitat less favorable for tick survival yet not so extreme as to make the bottom oak-hickory unsuitable, or that total tick production was lower as a result of fewer deer).

Semtner & Hair (1973b) reported peak activity of free-living larvae in Oklahoma in July and August. The current study showed that peak infestation of larvae in deer occurred at the same time, and deer utilization of different habitats was such that considerable larvae should have been dropped and nymphs should have been trapped in the meadow and upland oak-hickory habitats the following year (FIG. 10). The meadow habitat was unsuitable for survival of the replete larvae because few nymphs were trapped in this habitat the following year (FIG. 10). Nymphs were trapped most abundantly in the upland and bottom oak-hickory.

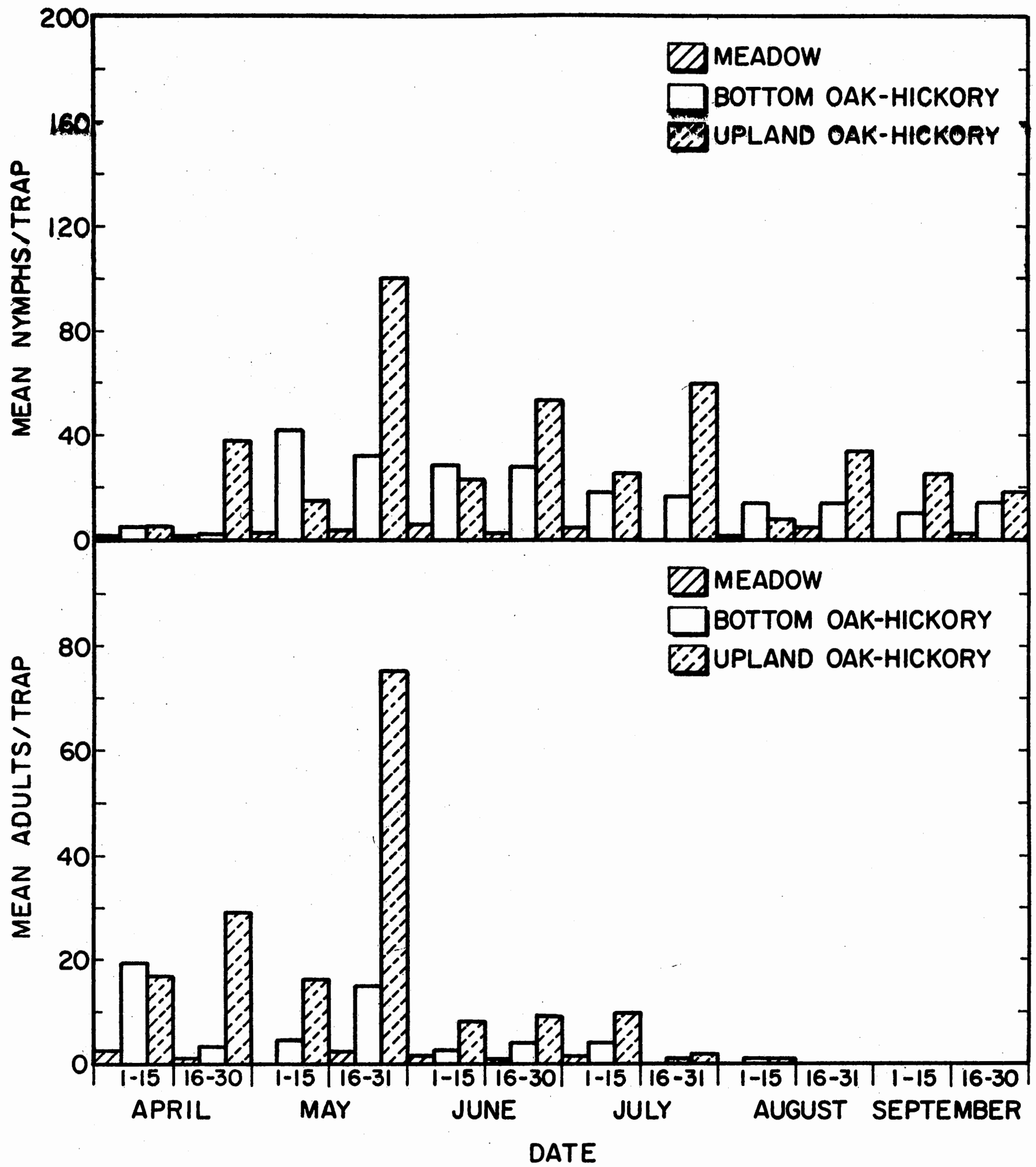

FIG. 9. Trapping of nymphs and adults in 3 habitats, 1974.

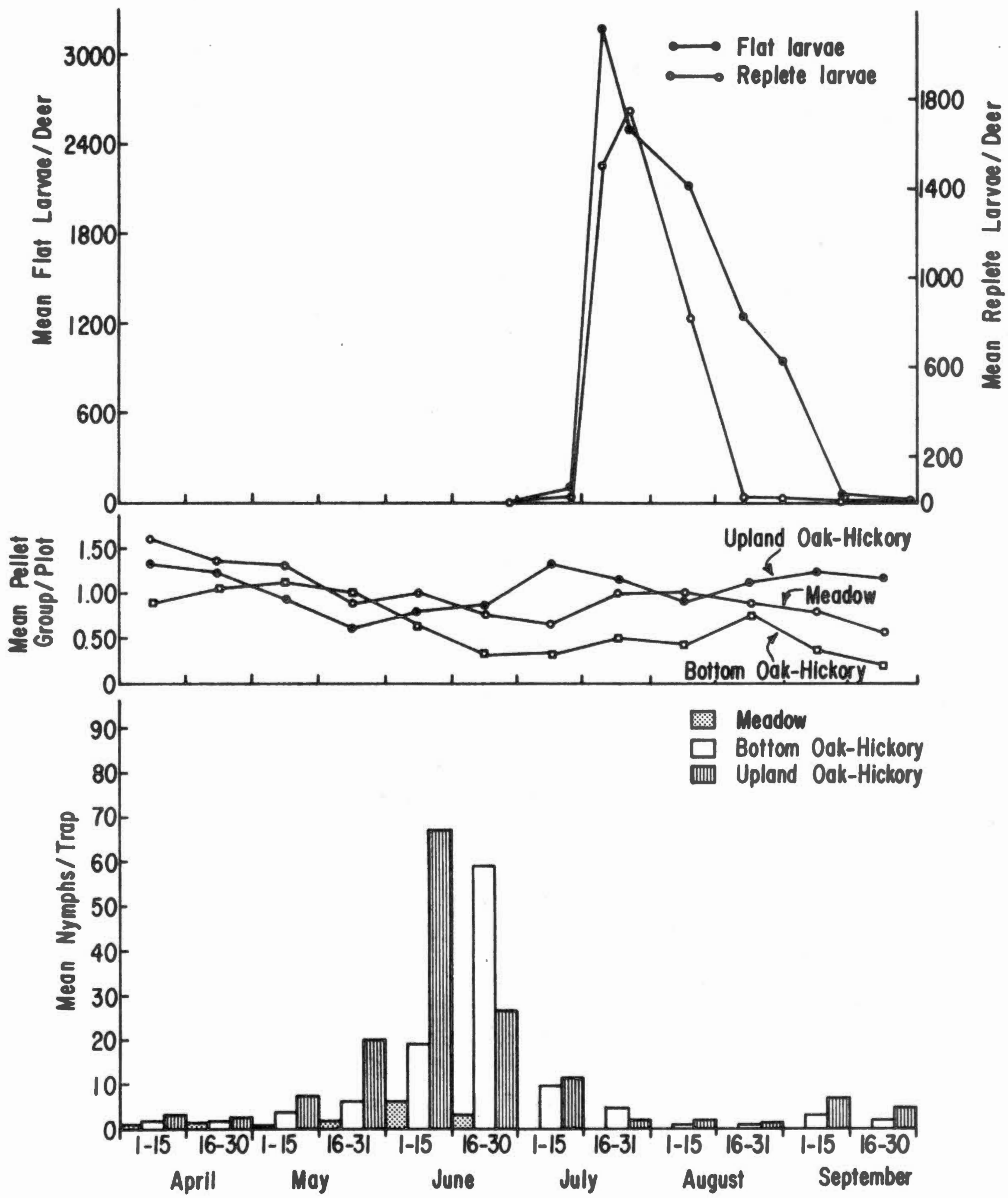

FIG. 10. Seasonal abundance of flat and replete larvae on deer in relation to utilization (avg. pellet group/plot), 1973, and adult in 3 habitats, 1974.

Again, the nymphal trapping results in 1974 did not reflect as low deer-use as those in 1973 (FIG. 9) because comparable numbers of nymphs were trapped in both habitats (FIG. 10). As discussed with larval and adult trapping the climatic conditions in 1974 were such that the upland oak-hickory became unsuitable for tick survival. The bottom oak-hickory was apparently not greatly affected by the rainfall reduction and lower total tick production.

Summary

The upland oak-hickory habitat supported large numbers of ticks as ascertained by CO_2 traps and under normal climatic conditions was suitable for tick survival, but under the climatic conditions that existed in 1974, even with continued high deer-use, it supported very low populations of ticks relative to a more normal year as 1973. The bottom oak-hickory habitat was capable of supporting a large population of ticks even under climatic conditions that existed in 1974, but the low deer-use prevented large numbers of ticks from being introduced there. The meadow habitat received relatively high use but climatic conditions were such that ticks did not survive there. Although deer-use introduced the lone star tick to the various habitats, climatic factors ultimately controlled the ability of the tick to survive.

CHAPTER IV

BEHAVIOR OF THE REPLETE FEMALE AND PERCENT EGG HATCH IN FOUR DIFFERENT HABITATS

Replete female lone star ticks [Amblyomma americanum (L.)] are introduced into various habitats by host utilization of these habitats. Since the mobility of completely engorged ticks is limited due to enlargement of the body (Balashov, 1972), the survival of the female and progeny is dependent upon the environmental factors that it encounters in the different habitats to which it is exposed. Robertson, et al. (1975), reported that temperature and humidity have the greatest effect upon the survival of replete nymphs and larvae. He reported that replete nymphs and larvae artifically introduced into a meadow during July and August with soil temperatures above 45°C succumbed. Lancaster & McMillan (1955) reported that lone star tick females exposed to 7, 25, and 47% relative humidity either did not oviposit or their eggs failed to hatch. They reported normal oviposition and hatching at 73 and 91% relative humidity. Sonenshine & Tigner (1969), in laboratory studies, indicated that oviposition of the lone star tick female was not influenced with humidities between 45-95%, but that hatching of eggs was influenced at humidities below 65% and no hatching below 55%. Robertson (1974) observed preoviposition behavior, preoviposition time, and egg incubation time of the female lone star tick in a wooded habitat but did not make comparisons with other habitats.

The purpose of this study was to make similar observations plus determine egg hatch % in 4 different habitats to determine habitat potential for supporting ticks and also to observe migration of replete females in varying amounts of ground cover.

Methods and Materials

Replete female lone star ticks were reared on sheep (Patrick & Hair, 1975) at the Oklahoma State University Tick Research Facility, Stillwater, Oklahoma, and released into 76.2 cm diameter arenas made of 20.32 cm high steel garden edging placed in different habitats in the Cookson Hills State Game Refuge in eastern Oklahoma. With a minimum of disturbance of the habitat, the arenas were buried in the soil ca 5 cm and a bead of Stickum Special^{R} was applied around the top of the edging to prevent escape of replete females and subsequent larvae. Monthly releases of replete females were made from early spring until late fall. During weekly observations, litter within the arena was gently lifted until the replete female could be observed and notes taken of preoviposition behavior, preoviposition time, and egg incubation time and then the litter replaced with only a minimum of disturbance to the habitat and the replete female.

The egg viability study required locating egg masses within the arena and observing until hatch. After hatch 3 egg masses were taken up and returned to the laboratory. Five hundred eggs were randomly selected from each of the 3 egg masses and unhatched eggs counted. The % hatch was attained and used as an indication of egg viability in the different habitats. Soil moisture % was determined in each habitat type (Hoch, et al., 1971) and related to the % egg hatch in that habitat.

Temperature and relative humidity were recorded continuously on 7-day charts with Belfort[R] hygrothermographs placed within standard weather stations located in 4 different habitats.

In the migration study replete females were released from marked points in a woodlot having varying amounts of ground cover. A 7.6 cm fluorescent monofilament line of fine diameter was attached to the dorsum of the replete females by contact cement. This facilitated finding ticks when ground cover became heavy and in preliminary trials did not appear to hinder their movement through leaves or vegetation. Two different releases were made in the woodlot, one on 8 May 1972 and another on 8 June 1972. A single release was made in the meadow to determine migrating behavior and to determine if there was oriented movement to a nearby woodlot. Observations were made weekly to determine how far the replete female had moved from the release point.

Results and Discussion

Preoviposition behavior. Replete females released into woodlot arenas moved to the duff layer (a layer of decaying leaf litter and detritus immediately above the soil, normally with high moisture and insulative properties), where they would be protected from all but extremely high temperatures and low humidities. In meadows, the replete females would congregate at the most favorable site or sites such as the base of clumps of grass and crevices in the ground within the arena. Lancaster (1973) reported similar observations of the lone star tick replete females in western Arkansas. It was not unique to find 5-8 ticks at a single site within the arena. This appeared to suggest selection of favorable sites by replete females. Frequent observations seemed to disturb the females and caused them to move from one oviposition site to another. Limiting observations to one per week lessened disturbance and allowed the females to become quite and remain at one site.

Preoviposition time. Sweatman (1967) defined the preoviposition period as that time between engorgement and the first day of egg-laying. He showed a definite correlation between preoviposition period of the brown dog tick [Rhipicephalus sanguineus (Latrille)] and temperature. With increased temperature the preoviposition time became shorter up to 30°C, at which point it began to lengthen again. Sweatman (1968) also observed the same behavior with Hyalomma aegyptium (Linneaus) except that the optimum temperature was higher. Similar findings were recorded for the lone star tick replete female but under field conditions we were unable to determine if there was an upper temperature limit on shortening preoviposition time. In 1973, preoviposition time varied from 36 days on replete females released in March to 7 days on ticks released in July (TABLE 2). In this study the upper temperature limit of shortening preoviposition time may have occurred in July since the preoviposition time was longer in August and temperatures were slightly higher (FIG. 2). Observations were not made frequent enough to determine the effect of temperature differences of the different habitats. A similar study was conducted in 1974 with similar results in that preoviposition time shortened from 49 days in March to 8 days in June and July with longer periods occurring in August again suggesting that an optimum temperature for decreasing preoviposition time occurred in June and July (TABLE 2).

Incubation time. While preoviposition time seemed inversely

TABLE 2. Preoviposition time of replete female lone star tick in 4 different habitats of Cookson Hills State Game Refuge in eastern Oklahoma, 1973 & 1974.

Release Date	Longevity (days)			
	Meadow	Persimmon	Upland Oak-Hickory	Bottom Oak-Hickory
1973				
21 March	36	36	36	36
20 April	25	25	25	35
24 May	22	22	22	22
21 June	8	8	8	8
20 July	7	7	7	7
20 August	8	8	8	8
21 September	9	9	9	9
2 October	No oviposition		No oviposition	
1974				
7 March	49	49	49	49
11 April	21	21	21	21
8 May	10	10	10	10
11 June	8	8	8	8
8 July	8	8	8	8
16 August	10	10	10	10

related to temperature, other authors reported that incubation time seemed to be more directly related to the relative humidity (i.e. as humidity increases incubation time increases). Lancaster & McMillan (1955) observed this phenomenon in western Arkansas with the lone star tick and MacLeod (1935) indicated that humidity was important in egg viability and its rate of development. While incubation time appeared to be closely related to relative humidity, it could not be completely separated from the effects of temperature under field conditions because as temperatures increased and humidities decreased egg incubation time became shorter from 64-76 days on eggs exposed from 26 April to 31-35 days on eggs exposed from 29 June and 27 July in 1973, and 55-68 days on eggs exposed from 25 April to 36 days on eggs exposed from 17 July in 1974 (TABLE 3). On subsequent egg exposure periods, 28 August 1973 and 16 August 1974, we noted an increase of incubation time to 67 days and no hatch, respectively. The studies in 1973 and 1974 also indicated that there was a difference of hatching time among habitats (TABLE 3). The meadow habitat had the shortest incubation with 31-67 days in 1973 and 40-55 days in 1974. Incubation time in the meadow may have been shorter in 1974 except that extreme soil surface temperatures in the meadow of 50°C was lethal to the eggs resulting in no hatch of eggs from the 19 June and 17 July exposure period. The bottom oak-hickory habitat had the longest egg incubation time of 35-76 days in 1973 and 36-68 days in 1974. Egg incubation time was similar in the persimmon and upland oak-hickory habitats.

Egg Hatch. In 1973, it appeared that the % egg hatch was related to soil moisture, because as soil moisture began decreasing in July and August the % egg hatch in the different habitats appeared to be reduced

TABLE 3. Egg incubation time of lone star ticks in 4 different habitats of Cookson Hills State Game Refuge in eastern Oklahoma, 1973 & 1974.

Release Date	Egg Incubation Time (days)			
	Meadow	Persimmon	Upland Oak-Hickory	Bottom Oak-Hickory
1973				
26 April	64	64	64	76
15 May	45	46	49	54
15 June	36	36	34	42
29 June	31	32	32	38
27 July	35	35	35	35
28 August	67	67	67	67
28 September	No hatch	No hatch	No hatch	No hatch
2 October	No hatch	No hatch	No hatch	No hatch
1974				
25 April	55	63	63	68
2 May	52	52	61	61
18 May	40	62	52	60
19 June		41	41	41
17 July		36	36	36
16 August	No hatch	No hatch	No hatch	No hatch

(especially in the meadow, FIG. 11). In 1974, the study was repeated but with different results (FIG. 12). The soil moisture was much lower in 1974 than in 1973 but no effect was noted except in the meadow where no eggs hatched in July and August. It seemed that there was contradicting data for the 2 years. Soil surface temperatures were measured during both studies and possibly explained the differences in data obtained. In 1974, with very low soil moisture (less than 3%) in all habitats, the only eggs that were affected were those in the meadow, where soil surface temperatures were above 50°C during egg exposure time. The tick egg has a wax layer that serves in preventing water loss from the egg (Balashov, 1972) laid down by the Gene's organ during oviposition. The critical temperature limit for breakdown of the wax layer of tick eggs is not known, but in insects the temperature limit usually exists between 40-50°C. When the temperature exceed the critical point, there is a rapid loss of water from the egg. This probably occurred in these 2 studies. As the temperature approached 40°C in the meadow the wax layer of the tick egg began breaking down causing water loss and subsequent lowering of egg hatch. As the temperature went above 45°C the effect on the eggs was so great that there was no hatch of eggs as occurred in the meadow in 1974. Apparently the wax layer enabled the egg to survive under very dry conditions except where the temperatures become so high as to break down the wax layer.

Migration. The lighter the ground cover and the higher the temperature in the woodlot, the greater was the migration distance of the replete female (TABLE 4). During the May 1972 release, females in the woodlot migrated an average of 8.64 cm in light ground cover as compared with 5.59 cm in heavy ground cover. With an increase in temperature

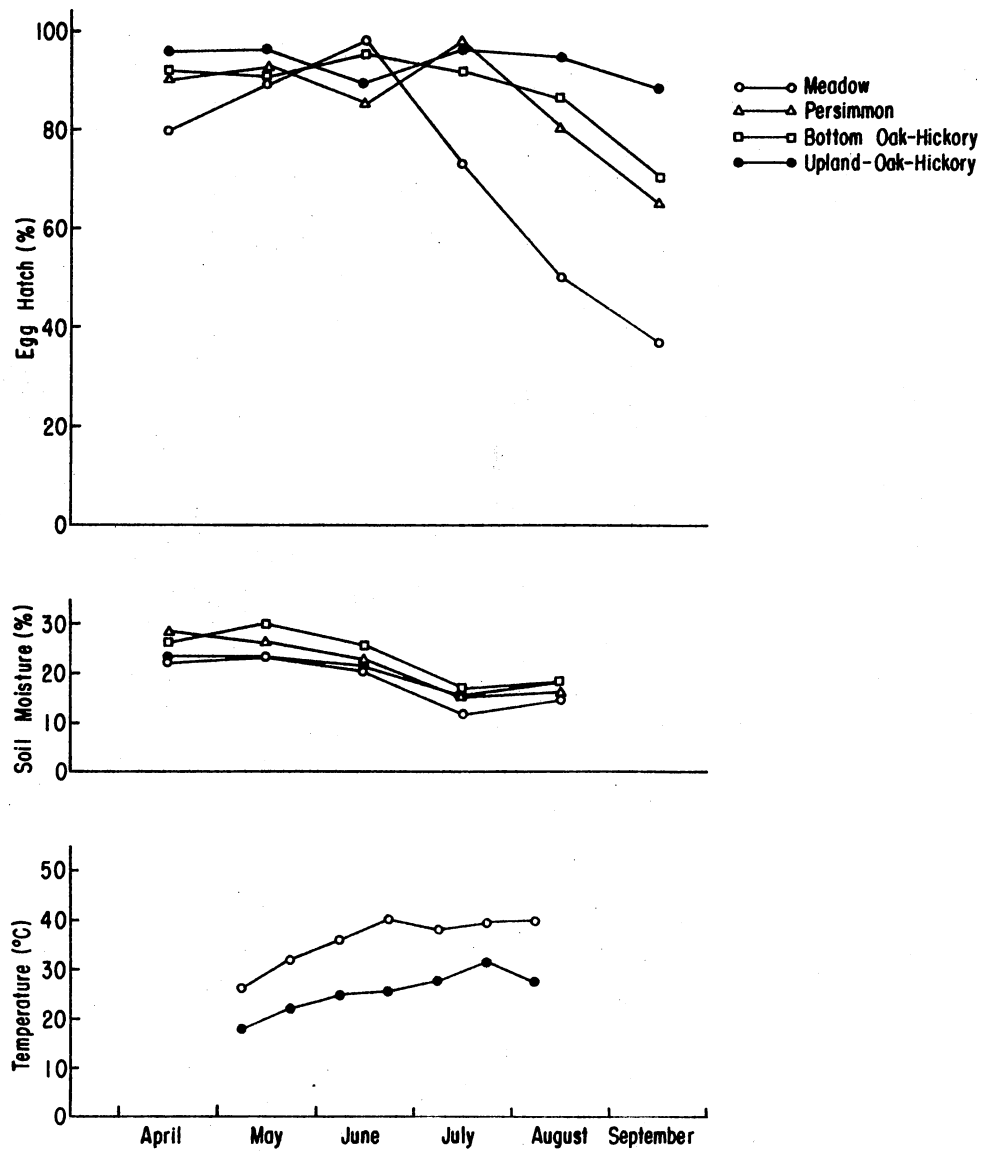

FIG. 11. Percent egg hatch in relation to soil moisture and soil surface temperature in 4 different habitats in Cookson Hills State Game Refuge in eastern Oklahoma, 1973.

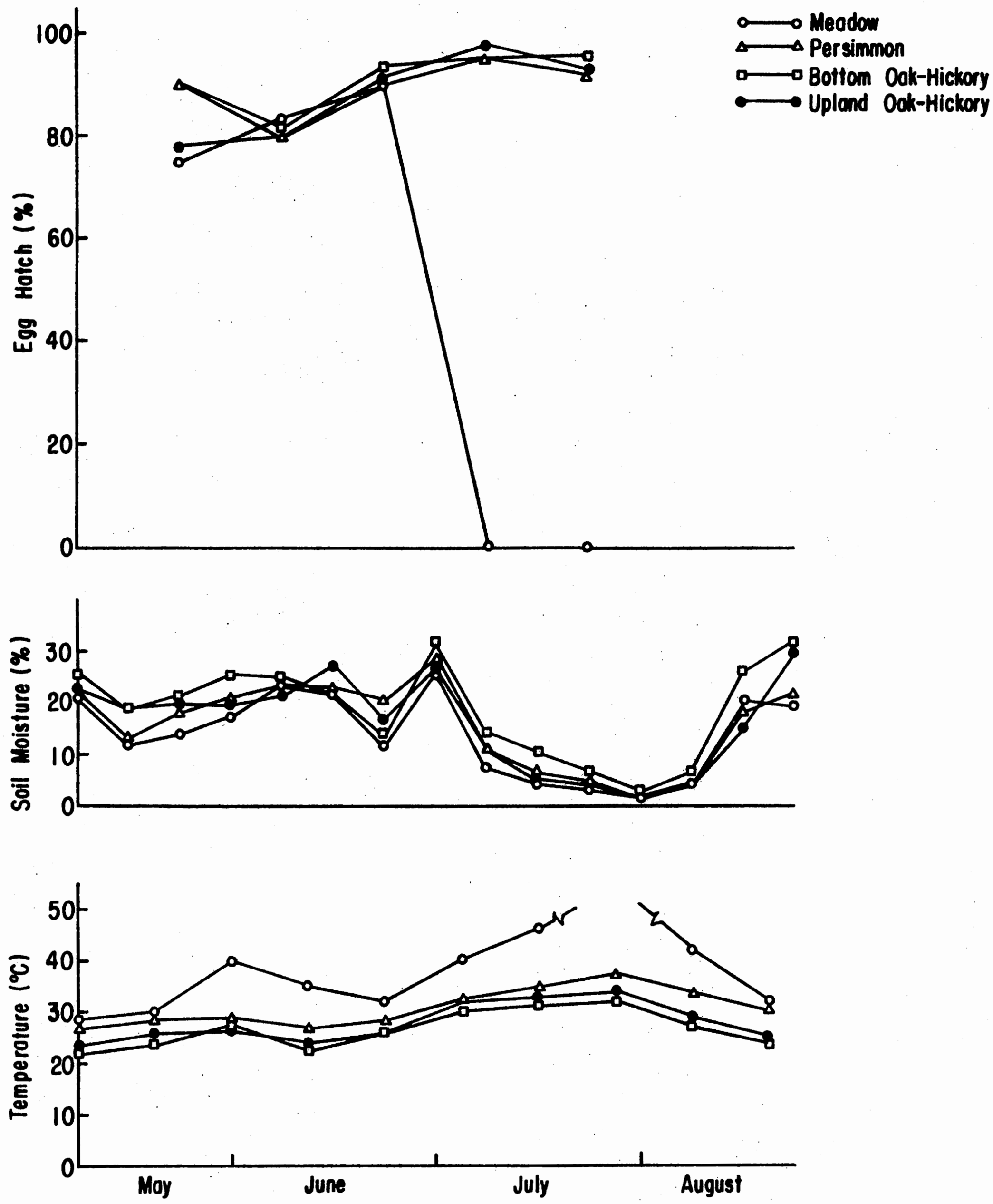

FIG. 12. Percent egg hatch in relation to soil moisture and soil surface temperature in 4 different habitats in Cookson Hills State Game Refuge in eastern Oklahoma, 1974.

TABLE 4. Migration of replete female lone star ticks in 2 different levels of ground cover within a woodlot of Cookson Hills State Game Refuge in eastern Oklahoma, 1972.

Release Date	Average Migration Distance (cm) and Range	
	Light Cover	Heavy Cover
8 May	8.64 (5.08-25.4)	5.59 (0-10.2)
8 June	60.96 (50.8-129.5)	9.35 (3.81-8.89)

(an average of 17.6° in May to 23.7°C in June), an increase in migration distance occurred in both habitats: 60.96 cm in light ground cover and 9.33 cm in heavy ground cover. This behavior seemed to indicate that fewer favorable oviposition sites were available in light ground cover as compared to heavy ground cover and that higher temperatures reduced favorable oviposition sites in both habitats. This resulted in increased movement of the replete female. A single release of replete females in the meadow migrated an average of 17.78 cm, at which point they were found dead and they had not initiated oviposition. Apparently they succumbed to the high temperatures experienced in the meadow. There was no indication of oriented migration to the nearby woodlot.

Summary

As determined by the migration study the replete female tick did not have the ability to remove herself from an unfavorable habitat; however, she apparently had limited ability to select the most favorable site within that habitat into which she dropped from a host. Observance of replete females in arenas determined that preoviposition time did not differ among habitats. Increased temperature decreased preoviposition time but the upper limit of temperature effect was not determined even though it appeared to be in effect. Incubation time did differ among habitats apparently in response to a combination of relative humidity and temperature. The ultimate success of the replete female in the habitat into which she dropped would be measured by her ability to oviposit and the eggs to hatch. In all habitats the eggs were successful in hatching except when soil temperatures exceeded 40°C at which point there was reduction in percent egg hatch. The meadow was the only habitat whose soil temperatures exceeded 40°C. Apparently the eggs were able to remain viable and hatch in habitats in which the subsequent larvae would be unable to survive.

CHAPTER V

BEHAVIOR AND LONGEVITY OF LONE STAR TICK LARVAE IN FOUR DIFFERENT HABITATS

In eastern Oklahoma, larval lone star ticks [Amblyomma americanum (L.)] begin activity in appreciable numbers in late June. They reached maximum numbers during late July and early August and continued in moderate numbers until freezing temperatures in the fall (Lancaster, 1957; Hair & Howell, 1970; Semtner, et al., 1973b). Semtner, et al. (1973b) noted as much as 2 months difference in peak larval activity among different habitats. Feldman-Muhsam (1947) reported that larval Hyalomma savignyi Gerv. were more sensitive to humidity than to temperature. Lancaster & McMillan (1955) in laboratory studies, indicated similar findings. They reported that lone star tick larvae exposed to humidities of 51 to 59% or lower resulted in complete mortality in 2 days. These may not be realistic values since they were observations of 40 individual larvae and not masses of larvae of several thousand that have been observed under field conditions. Several other studies exist on larvae of other ticks such as the sheep tick [Ixodes ricinus L.], (Lees & Milne, 1951); the blue tick [Boophilus decoloratus (Koch)], (Goldsmid, 1967); and the cattle tick [B. microplus (Canestrini)], (Wilkerson, 1953). These authors dealt little with longevity except under laboratory conditions. Under field conditions, Hooker, et al. (1912) reported lone star tick larvae surviving for 279 days.

In order to evaluate a habitat as potentially supporting large numbers of ticks one must know how the environmental conditions of that habitat affect the survival of the larvae and their potential for finding a host. The purpose of this study was to observe behavior and determine longevity of lone star tick larvae in relation to temperature and humidity that existed in 4 different habitats.

Methods and Materials

Masses of field larvae were attained by the releasing of replete females in the particular habitats in which we desired to study the survival of the larvae. Replete females were reared on sheep at the Oklahoma State University Tick Research Facility, Stillwater, Oklahoma (Patrick & Hair, 1975). Arenas of steel garden edging 76.2 cm in diameter and 20.32 cm high were buried in the soil approximately 5 cm in the soil of 4 different habitats (meadow, persimmon, upland oak-hickory, and bottom oak-hickory). Monthly releases of 12 replete females per arena were made from March through August in each habitat. Frequent observations were made of the replete female to determine when oviposition and subseqent hatching of the eggs occurred. Post-hatch development, movement, and longevity of the larvae were determined for each habitat. Temperature and humidity were recorded continuously on 7-day charts with Belfort[R] hygrothermographs within standard weather stations located in each habitat and related to observations of larvae.

Results and Discussion

Post-hatch development varied with the season from 10-16 days after eggs hatched in late June to early July and 20-29 days after eggs hatched in late July and August. Robertson (1974) observed similar but shorter trends in post-hatch development. He recorded 2-5 days post-hatch development early in the season and 10-15 days late in the season in a persimmon habitat. These differences may be the result of his releasing newly hatched larvae whereas in this study replete females were released and since hatch time was not noted it has been recorded as part of the post-hatch development. Lancaster (1957) reported a 3-18 day hatching time of lone star tick eggs, which may account for the considerable difference between Robertson's (1974) observations and these. In view of the above information it was possible that under the conditions that existed earlier in the season (lower temperatures and higher humidities) the larvae developed a positive phototactic response (Wilkerson, 1953; MacLeod, 1935) much sooner than later in the season. Since under natural conditions, larvae are exposed to the most extreme conditions that may be detrimental to their survival, this behavrior of extended post-hatch development under conditions of high temperature and low humidity may have survival value because they may not become positively phototactic until more favorable conditions exist.

Larvae ascended the vegetation to heights ranging from 5-76 cm, and most were observed at approximately 30 cm. Little movement of larvae was noted once they ascended the vegetation. The extensive vertical migration that Milne (1946) observed in I. ricinus was not observed in lone star tick larvae. Hair & Howell (1970) observed only 2 basic movements of ascended larvae; (1) avoidance of impinging sun rays; (2) minor movement in response to a host; likewise, these were the only movements noted of ascended larvae in this study.

Table 5. Survival of lone star tick larvae in 4 different habitats of Cookson Hills State Game Refuge in eastern Oklahoma, 1973 & 1974.

Release Date	Longevity (days)			
	Meadow	Persimmon	Upland Oak-Hickory	Bottom Oak-Hickory
1973				
21 March	19	64	87	106
20 April	12	54	52	66
24 May	10	31	31	34
21 June	14	20	31	40
20 July	-	14	20	35
1974				
7 March	14	28	25	45
11 April	10	25	24	30
8 May	10	20	20	36
11 June	-	14	23	38
9 July	-	14	25	33

Larval survival varied considerably among the different habitats (TABLE 5). Larvae in the meadow habitat had the shortest survival time of 10-19 days in 1973 and 10-14 days in 1974. In contrast the bottom oak-hickory had the longest survival of 34-106 days in 1973 and 33-45 days in 1974. Semtner, et al. (1971b) reported the greatest survival of adults in the bottom oak-hickory because of lower temperatures and higher humidities as compared to other habitats. Apparently the same factors allowed larvae to survive longer in this habitat. Although not recorded, more exposure to the wind and rain may have been instrumental in shorter survival in the meadow than in the wooded habitats. Hair & Howell (1970) reported that heavy rains and strong winds rended to dislodge larval masses, with less than 10% of the mass able to regroup. This caused considerable mortality as a result of loss of their collective ability to withstand environmental stress. The persimmon and upland oak-hickory habitats have similar survival patterns until the 21 June and 11 June releases in 1973 and 1974, respectively. Apparently the increased temperatures and lower humidities at this time (FIG. 2) caused the persimmon to become less favorable for larval survival. Overall survival for the 2 years is also different. Lower temperatures and higher humidities (FIG. 2) and above average precipitation (TABLE 1) in 1973 allowed longer survival than did the warmer and dryer conditions of 1974 (FIG. 2, TABLE 1).

Summary

Higher temperatures and lower humidities extended post-hatch development of larvae that were attained from released replete females in arenas of various habitats. This may have survival value for the

larvae because they would not be as likely to ascend vegetation until conditions more suitable to their survival existed, thus exposing them longer to hosts. Once the larvae have ascended the vegetation their only movement was in response to the sun and hosts. The longest survival of larvae occurred in the bottom oak-hickory habitat, but their host-finding potential in this habitat was low because deer did not utilize this particular habitat extensively, offsetting any value that longevity may have afforded the larvae in host-finding. Larval longevity was similar in the persimmon and upland oak-hickory habitats, but shorter than that observed in the bottom oak-hickory. The potential of finding a host was high because these 2 habitats received high deer-use. The meadow had the shortest larval survival but received relatively high deer-use resulting in a poor host-finding potential because of short exposure period.

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APPENDIX

TABLE 6. Monthly average of ticks trapped by CO_2 traps in 3 different habitats of Cookson Hills State Game Refuge in eastern Oklahoma, 1973.

Month	Tick	Meadow	Bottom oak-hickory	Upland oak-hickory
April	female	4.67	26.33	77.33
	male	4.00	25.33	73.00
	nymph	5.33	9.67	293.00
	larvae	0	0	0
May	female	5.25	45.50	191.00
	male	5.50	30.50	173.25
	nymph	7.75	103.75	213.75
	larvae	0	0	10.50
June	female	5.67	12.17	25.17
	male	3.33	7.33	18.33
	nymph	30.17	93.67	84.67
	larvae	0	0	0
July	female	4.20	9.40	20.00
	male	1.20	7.40	18.40
	nymph	6.80	39.40	148.00
	larvae	40.40	21.20	536.40
August	female	0.25	1.25	1.75
	male	0	0.75	1.00
	nymph	6.75	51.50	70.25
	larvae	514.25	364.25	643.75
September	females	0	0.25	0
	male	0	1.25	3.50
	nymph	2.25	37.50	46.75
	larvae	27.25	120.00	137.50

TABLE 7. Monthly average of ticks trapped by CO_2 traps in 3 different habitats of Cookson Hills State Game Refuge in eastern Oklahoma, 1974.

Month	Tick	Meadow	Bottom oak-hickory	Upland oak-hickory
April	female	1.00	5.00	7.71
	male	1.28	6.43	6.21
	nymph	4.86	7.57	14.14
	larvae	0	0	0
May	female	1.45	8.27	13.00
	male	1.00	7.64	14.27
	nymph	7.63	27.45	77.00
	larvae	0	0	0
June	female	2.50	12.57	19.00
	male	2.78	11.78	13.43
	nymph	24.85	172.78	235.64
	larvae	0.86	0.50	0.86
July	female	0.17	2.23	2.76
	male	0	1.65	1.88
	nymph	1.41	30.94	26.88
	larvae	2.17	83.94	74.00
August	female	0	0.07	0
	male	0	0	0
	nymph	0.14	3.78	6.71
	larvae	0.14	11.00	64.57
September	female	0	0	0
	male	0	0	0
	nymph	1.50	12.50	22.75
	larvae	0	3.25	7.50

TABLE 8. Monthly average of flat ticks on deer in Cookson Hills State Game Refuge in eastern Oklahoma, 1973.

Month	Female	Male	Nymph	Larvae
May	78.50	190.00	192.78	0
June	147.72	754.54	302.27	0
July	106.15	776.92	221.15	1879.23
August	11.00	20.92	442.30	1465.38
September	1.80	2.50	227.50	55.00
October	0	1.60	28.00	90.00
November	0	3.00	0.14	0
December	0	3.33	0	0

TABLE 9. Monthly average of replete ticks on deer in Cookson Hills State Game Refuge in eastern Oklahoma, 1973.

Month	Female	Nymph	Larvae
May	0.22	0	0
June	17.91	60.00	0
July	13.30	35.38	992.69
August	0.30	23.22	394.61
September	0.10	9.00	2.50
October	0	0.60	36.00
November	0	0	0
December	0	0	0

TABLE 10. Monthly average of flat ticks on deer in Cookson Hills State Game Refuge in eastern Oklahoma, 1974.

Month	Female	Male	Nymph	Larvae
January	0.08	1.78	1.52	0
February	0.75	7.00	12.75	0
March	26.33	41.17	67.5	0
April	39.30	145.00	232.50	0
May	80.83	287.50	254.17	0
June	76.33	618.33	235.00	6.67
July	55.37	121.12	273.43	201.25
August	2.00	3.22	103.89	430.56
September	0.81	1.50	38.12	381.25
October	0.20	0.40	7.00	29.00
November	0	0.44	1.11	0
December	0	3.60	0	0

TABLE 11. Monthly average of replete ticks on deer in Cookson Hills State Game Refuge in eastern Oklahoma, 1974.

Month	Female	Nymph	Larvae
January	0	0.04	0
February	0.08	1.58	0
March	0.16	0	0
April	0.10	11.60	0
May	4.17	9.17	0
June	7.40	42.33	6.67
July	5.68	77.18	41.25
August	0.11	42.33	179.44
September	0	5.75	51.87
October	0	0.80	5.00
November	0	0	0
December	0	0	0

TABLE 12. Monthly average of pellet groups per habitat in Cookson Hills State Game Refuge in eastern Oklahoma, 1973.

Month	Meadow	Bottom oak-hickory	Upland oak-hickory
April	1.48	0.95	1.26
May	1.05	1.02	0.76
June	0.87	0.46	0.80
July	0.80	0.40	1.25
August	0.96	0.61	1.01
September	0.67	0.33	1.23

TABLE 13. Monthly average of pellet groups per habitat in Cookson Hills State Game Refuge in eastern Oklahoma, 1974.

Month	Meadow	Bottom oak-hickory	Upland oak-hickory
April	1.50	0.42	0.74
May	1.04	0.49	0.82
June	0.24	0.58	1.15
July	0.63	1.00	1.68
August	0.75	0.61	1.59
September	0.94	0.33	1.49

VITA

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Doctor of Philosophy

Thesis: RELATIONSHIP OF LONE STAR TICKS [AMBLYOMMA AMERICANUM (LINNEAUS)] AND WHITE-TAILED DEER [ODOCOILEUS VIRGINIANUS (BODDAERT)] IN CHEROKEE COUNTY, OKLAHOMA

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