FIELD STUDIES ON THE POPULATION BIOLOGY OF IMMATURE STAGES OF SIX WOODLAND MOSQUITO SPECIES IN THE HOUSTON, TEXAS AREA[1]

DONALD R. ROBERTS[2,3] AND JOHN E. SCANLON[2]

ABSTRACT. A program of field studies on the immature stages of *Aedes atlanticus* D. & K., *Ae. tormentor* D. & K., *Psorophora ferox* (Humboldt) *Ps. longipalpis* Randolph and O'Neil, *Ps. ciliata* (Fabricius) and *Ps. howardii* Coquillett was conducted in Houston, Texas 1971–72. Woodland pools, upon formation, were sampled with the standard pint dipper method and emergence traps. In May, 1972, an area sampler was employed to study natural developmental rates of the various species. Collections were made to calculate developmental rate estimates, compare pools in various habitats for presence of the above species, study population distributions and seasonal abundance.

During the summer months the species included in these studies were dominant in woodland temporary pools and only *Ae. infirmatus* did not have a diapause egg stage during mid-winter. These species seem to be multivoltine. Seven species demonstrated a developmental time from egg to pupae of 7–8 days. *Aedes fulvus pallens* required 12–15 days to become pupae and commonly emerged from pools without standing water. Only larvae of *Ae. atlanticus* and *Ps. longipalpis* were common in the field, ecotone and woodland pools. Other species were more common in woodland, fully shaded pools.

Comments are presented on the various sampling methods and impact of species variability in behavior on numbers of larvae collected.

INTRODUCTION

A program of ecological studies on woodland mosquitoes was conducted in Houston, Texas 1971–72. Included were studies on the biology of the adults and immature stages of *Aedes atlanticus* D. & K., *Ae. fulvus pallens* Ross, *Ae. infirmatus* D. & K., *Ae tormentor* D. & K., *Psorophora ferox* (Humboldt), *Ps. lognipalpis* Randolph and O'Neill, *Ps. ciliata* (Fabricius) and *Ps. howardii* Coquillett. Larvae of these species are found in temporary pools associated with woodland areas (King et. al. 1960, Breland 1961, Carpenter et. al. 1946, Travis 1969, and Gerhardt 1966). They occur in discrete populations and commonly with high population densities.

Specific objectives of studies reported here were to determine seasonal occurrence, determine developmental rates of the immature stages, study population distributions, compare sampling methods, and study species distribution by habitat. The observations on the adult populations of these species have been reported elsewhere (Roberts and Scanlon 1975).

[1] This work was supported by Research Contract Number DA DA 17–72–C–2022 from the U.S. Army Medical Research and Development Command, Office of the Surgeon General, Washington, D.C. The opinions contained herein are those of the authors and should not be construed as official or reflecting the views of the Department of the Army.

[2] The University of Texas Health Science Center at Houston, School of Public Health, P.O. Box 20186, Houston, Texas 77025.

[3] Major, MSC, U.S. Army, presently assigned as Chief, Medical Entomology, United States Army Medical Research Unit-Brasilia, APO Miami 34030, with appointment as Professor Visitante, Universidade de Brasilia, Faculdade de Ciencias da Saude, Nucleo de Medicina Tropical e Nutriçao, Brasilia, D.F., Brasil 70.000.

MATERIALS AND METHODS

STUDY AREA. The studies were conducted at the University of Houston Gulf Coast Research Station located 45 km southeast of Houston in Hitchcock, Texas. The study area was described by Joule and Jameson (1972). The specific study site was a grove of Chinese tallow trees 1.4 ha in size bordered by roads to the north, south and east and an old field to the west.

The topography of the woodland and field area was flat and pools of standing water were abundant during periods of heavy precipitation. The water-flow through the woodland area was north-south and with small rains only the most northern location of the study area had standing water (pool A).

SEASONAL OCCURRENCE. The monitoring program was conducted from November, 1971 through October, 1972. The study area was checked weekly for presence of standing water. The standard method of dipping for larvae was used throughout the program. However, a cylindrical area sampler was designed, evaluated and employed in field sampling May-November, 1972 (Roberts and Scanlon 1974). The sampler consisted of a plain outer cylinder which was placed in the pool and seated in the mud. An inner chamber, with an inverted funnel, was then placed in the outer chamber. After waiting 15 to 20 min the inner chamber was removed and larvae were poured into a pan, hand-picked and preserved.

DEVELOPMENTAL RATES, POPULATION DISTRIBUTIONS AND COMPARISON OF SAMPLE METHODS. A series of paired samples was collected from 2 woodland pools (pools A and B). Recordings of water temperatures were made when samples were collected. Pool A, at the far northern edge of the wooded area, was flooded 8 May and pool B was flooded 10–11 May 1972. Area samples were collected along 2 transects in each pool. A dip sample was collected 30 min later from the locale where an area sample had been collected. A 4 ft wood handle was used with the dipper to minimize disturbance to the larvae. The sequence of collecting dip vs area samples was reversed the following day. Samples were collected daily from 8 May 1972 until both pools were dry, a total of 15 days (Table 1).

In the course of these studies it was important to identify the 6 species in all immature stages. This was accomplished by utilizing existing keys (Carpenter and LaCasse 1955 and Dodge 1966) and by detecting additional characters for species separation where needed (Roberts 1973). However, it was not possible to separate the pupae of female *Ps. longipalpis* and *Ps. ferox*, or for either sex of *Ps. ciliata* and *Ps. howardii*.

The 2nd and 3rd stage larvae were eventually summed together because of difficulties in separating these stages for all species. Presence of the egg burster identified 1st stage larvae. Fourth stage larvae were recognized by the anal segment being fully encircled by the saddle (Carpenter and LaCasse 1955).

Samples from pool B were used to estimate the developmental rates for the 3 most abundant species. This pool was subjected to only 1 secondary flood 2 days after being filled initially. However, due to small numbers of *Ae. atlanticus, Ae. tormentor* and *Ps. howardii-ciliata* it was necessary to combine collections from pools A and B to have sufficient numbers for estimating their developmental rates. Collections from both pools were adjusted to a common starting point (day 1), since pool A was formed before pool B.

Emergence traps were used to establish the time of adult emergence. During May a floating-type trap was used that covered 205 cm² of water surface. This trap

Table 1. Dates of pool formation and longevity at the Gulf Coast Research Station, Hitchcock, Texas.

Date	Pools filled* w/water	Pool longevity (days)
September 1971	All Pools	unknown
November 1971	All Pools	Nov. 71/Feb. 72
7–8 May 1972	Pool A	15
10–11 May 1972	All Pools	14**
July 1972	Pool A	4
August 1972	Pool A	4
September 1972	All Pools	14**

* The term "all pools" describes a condition of general flooding of all pools in the area, including study pools A, B and K. Only pool A was flooded in July and August.

** Pool longevity from observations on study pools A and B.

proved inadequate since many pools dried before adult emergence was completed. A stationary-type emergence trap was used when the pools were reflooded in September 1972. It consisted of a 5-gal metal can with the top and bottom removed. The can was placed in the pool with the end firmly wedged in the mud, the top was then covered with a cloth screen. Collections were made by lifting a small section of the screen and aspirating the adults with a mechanical aspirator.

The population distributions were studied by compiling a frequency distribution of numbers of larvae, for each species, collected in 6 area and 6 dip samples from pool A, 10 May 1972. Frequency distributions were also compiled for *Ae. fulvus pallens* 1st and 2nd stage larvae from area samples for 3 days, 1st and 2nd stage larvae from dip samples for 3 days and larvae from mixed collections during varying time intervals. The same distributions were compiled for collections of *Ps. longipalpis* larvae. A test for goodness of fit to the Poisson distribution was calculated on each frequency distribution (Remington and Schork 1970). Significance was established at the 0.025 level of probability.

To compare the size of catch by immature stage and sample method (the dipper vs the area sampler) the total numbers by genus, sample method and immature stage were summed for all paired samples collected during May 1972. These values were then used in a chi-square test to examine the hypothesis of no difference in numbers collected at the 0.05 probability level (Remington and Schork 1970).

SPECIES DISTRIBUTION BY HABITAT. A study of species distribution by habitat was conducted during October 1972. The study pools were located in the central area of the woodland, tree line and tree-lined roadside ditches and old fields adjacent to the wooded areas. Pools were sampled by dipping for larvae and emergence trapping. Each pool was transected twice with 20-30 dips. Emergence trapping was conducted in 1 pool per habitat with 3 traps per pool.

RESULTS

SEASONAL ABUNDANCE. Monitoring of woodland pools was initiated in the fall of 1971. Extensive rain, the first since the fall of 1970, was received at the study area in September, 1971 (Table 1). The subsequent appearance of dense populations of *Ae. tormentor, Ae. infirmatus, Ps. ferox* and *Ps. longipalpis* in man-biting collections indicated that a large hatch of these species had occurred. *Ae. fulvus pallens* adults were probably present at this time, but were not detected since collections were made only during daylight hours. No additional collections of adults were made until May of 1972.

The woodland pools were flooded several times during 1971–72 (Table 1). The pools had standing water continuously during the winter months. The initial populations in these pools consisted almost entirely of *Ae. vexans* (Meigen), with 2% represented by *Ae. infirmatus* larvae. Afterwards, populations of *Culex restuans* Theob. were dominant during the last half of December. In early January, 1972 there were approximately equal numbers of larvae of *Culiseta inornata* (Will.), *Cx. restuans* and *Cx. salinarius* Coq.

The Houston area received large amounts of rainfall in the 3rd week of March but no pools were formed at the field study area. Collections made in a woodland area within the city of Houston revealed an initial hatch of *Ae. atlanticus, Ae. tormentor, Ae. infirmatus* and *Ps. ferox*; but *Ae. vexans* was still the most abundant species found in the pools at that time.

Species represented in samples collected from pools A and B during May were *Ae. atlanticus, Ae. tormentor, Ae. fulvus pallens, Ps. ferox, Ps. longipalpis, Ps. ciliata* and *Ps. howardii*. Values for relative abundance of these species are presented in Table 2.

Pool A was reflooded in July, and a continuous 5-day series of area samples was collected. The populations of *Ae. tormentor* represented, proportionately, the most abundant species in that pool. Populations of *Ps. cyanescens* (Coq.) were

Table 2. Comparative densities of 6 mosquito species in woodland pools at the Gulf Coast Research Station in Hitchcock, Texas.

Month	Pool	% Sample population represented by each species						Type of sample	Number collected		
		Ae. atl.	*Ae. torm.*	*Ae. f.p.*	*Ps. ferox*	*Ps. longi*	*Ps. cil.* & *Ps. how.*		Totals[a]	Samples	$\overline{X}$
Nov. Feb. 71	All pools	0	0	0	0	0	0	Dip	—	—	—
May 72	A	2.1	3.3	10	24.5	56	4.5	Area	584	58[b]	10.7
May 72	B	8.9	4.5	5.7	34.7	35	11	Area	314	44[b]	7.14
July 72	A	3.4	39.3	10.7	9.0	22.5	15.2	Area	178	18[c]	9.9
Aug. 72	A	0.7	0.7	3.5	35.9	49.3	9.2	Area	141	15[d]	9.4
Sep. 72	A	0	7.3	0	53.7	39.0	2.4	Area	41	7[2]	5.8
Sep. 72	K	5.6	5.6	0	50.9	30.2	7.5	Area	53	5[e]	10.6
Nov. 72	A,B,K	0	0	0	0	0	0	Dip	—	—	—

[a] Based on totals of listed species.
[b] Collected over a 14 day period.
[c] Collected over a 5 day period.
[d] Collected over a 4 day period.
[e] Collected during 1 day.

present in relatively small numbers. Pool A was flooded again in August, and the *Psorophora* species represented the bulk of the mosquito fauna, and there was an overall reduction in the proportionate numbers of the 3 *Aedes* species. A similar population distribution was found in pool A when all pools were flooded in September.

The woodland pools became dry the latter part of October and were reflooded the 1st of November. Area samples were not collected in those pools since larvae of the woodland species, excluding *Ae. infirmatus*, were not present.

COMPARISON OF SAMPLE METHODS. Approximately twice as many larvae of both genera were collected with the area sampler compared to the dipper. Comparisons of *Aedes* species showed that a significantly greater proportion of 1st stage larvae were obtained by the dip method than the area sampler (Table 3). Approximately equal proportions of 2nd and 3rd stage larvae were collected by the 2 sampling methods, but significantly smaller proportions of pupae and 4th stage larvae were collected with the dip method. The data for the *Psorophora* species, *Ps. ferox* and *Ps. longipalpis*, showed no significant differences in sampling accuracy between the 2 sampling methods for the different immature stages.

POPULATION DISTRIBUTIONS. The population distributions of larvae were expected to be random (Poisson distribution) or clumped (negative binomial distribution) (Southwood 1971). Populations of *Ae. atlanticus, Ae. tormentor, Ae. fulvus*

Table 3. Efficiency of 2 sample methods in collecting immature stages of *Aedes* and *Psorophora* mosquitoes, evaluated with data from 52 paired samples (numbers in brackets represent counts of *Psorophora* mosquitoes).

Sample method	Number collected by immature stage				Total number collected
	I	II & III	IV	Pupae	
Area	23 (23)	45 (341)	21 (129)	21 (26)	110 (561)
Dip	25 (32)	24 (131)	3 (43)	9 (13)	61 (219)
Expected[a]	13 (25)	25 (133)	12 (50)	12 (10)	61 (218)

[a] Numbers expected for the dip sample method if distribution of numbers collected were the same as the area sampler.
*** Chi-square ($p<0.001$) for *Aedes* mosquitoes.

pallens, and *Ps. howardii-ciliata* were found to be Poisson distributed. The finding was based on analysis of the frequency distributions of numbers of 2nd and 3rd stage larvae collected in 6 area and 6 dip samples from pool A, 10 May 1972. A total of 125, 95, 7, 10, 18 and 18 larvae of *Ps. longipalpis, Ps. ferox, Ps. howardii-ciliata, Ae. atlanticus, Ae. tormentor* and *Ae. fulvus pallens* were collected, respectively, in the 12 samples. Populations of *Ps. ferox* and *Ps. longipalpis* were found to be clumped.

Collections of *Ae. fulvus pallens* and *Ps. longipalpis* larvae were studied to try to explain these observed differences. Analysis of area samples collected over a 3-day interval, in pool A, showed that 1st and 2nd stage *Ae. fulvus pallens* larvae were Poisson distributed. Samples collected with the dipper during the same interval did not show the population to be Poisson distributed. Tests with 2nd and 3rd stage *Ae. fulvus pallens* larvae were found to be strongly affected by the interval of time over which the samples were collected. If collections were from the same pool covering a period of 1-2 days, the distributions were Poisson. The distribution was not Poisson if collections for several consecutive days were pooled. Populations of *Ps. longipalpis* tested in the same combinations of instars, and days as employed with *Ae. fulvus pallens*, were not Poisson distributed.

Developmental Rates of Immature Stages. The developmental rates were calculated from daily collections of larvae with the area sampler. Rates were estimated on the basis of that day when 50% of the total number collected for each species had molted to the next stage. The range limits for water temperatures in the study pools were 17.5° and 23°C. *Ae. atlanticus, Ps. howardii, Ps. ferox* and *Ps. ciliata* showed the most rapid developmental rates (Table 4). Interestingly, the development of immature stages of *Ae. fulvus pallens* was clearly prolonged in comparison with the other species.

The temporal pattern of emerging adults in the floating emergence traps resembled the distribution in developmental rates of the immature stages (Fig. 1). A second series of collections was made with the stationary emergence trap in the woodland pools in September and October. The emergence patterns were similar with peak emergence of *Ae. fulvus*

Table 4. Developmental rates of 6 mosquito species expressed by 50% molting day (range). Estimates based on daily collections from woodland pools at the Gulf Coast Research Station, Hitchcock, Texas.

Species	Total collected	Duration of immature stages in days[b] I	II & III	IV	Pupae
Ae. atlanticus	51[a]	1 (1–3)	3 (2–5)	4 (3–8)	7 (6–8)
Ae. tormentor	50[a]	2 (1–2)	3 (2–4)	5 (5–6)	8 (7–10)
Ae. fulvus pallens	107	2 (2–4)	3 (2–9)	9 (8–15)	13 (12–15)
Ps. ferox	155	1 (1–3)	4 (2–5)	6 (4–8)	7 (6–8)
Ps. longipalpis	132	1 (1–3)	4 (2–5)	7 (5–9)	8 (7–9)
Ps. howardii & *Ps. ciliata*	48[a]	1 (1)	3 (2–4)	6 (4–8)	7 (7–8)

[a] Combined data from Pools A & B.

[b] Sequential sample days post-flooding of the study pool, *e.g.*, 7 in the 1st row indicates that on the 7th day post-flooding 50% or more of all specimens of *Ae. atlanticus* were pupae. Values in brackets present the 1st and last sequential sample days in which specimens of each immature stage were represented in the samples.

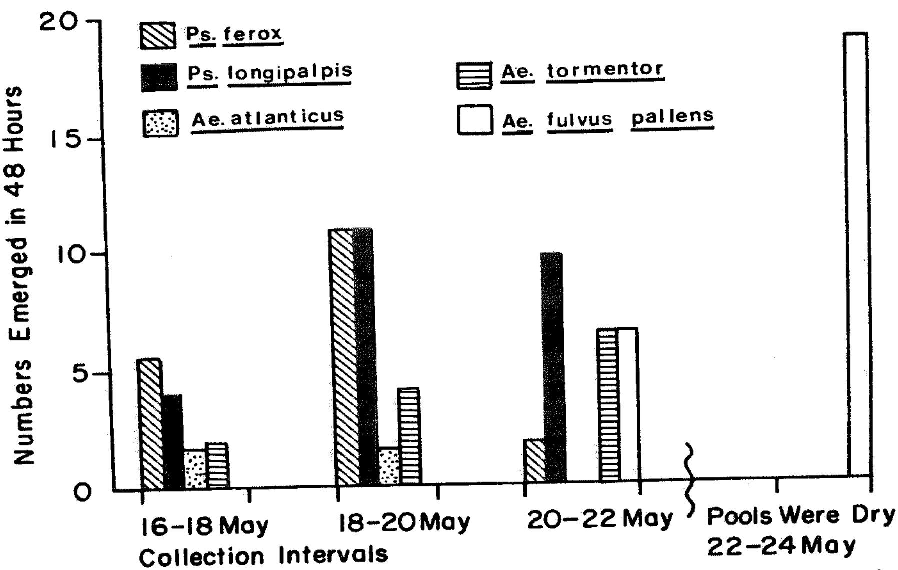

Fig. 1. Pattern of adult emergence of 5 species of woodland mosquitoes from 2 pools at the Gulf Coast Research Station in Hitchock, Texas. The last interval was 15–16 days after the pools were initially flooded.

pallens 15–16 days following initial flooding of the woodland pool. At that time the pools did not contain standing water and the adults emerged from the mud. In fact, all species included in this study were demonstrably capable of emerging from pools without standing water.

ABUNDANCE OF LARVAE BY HABITAT. Included in this study were field pools that were exposed to full sun, partially shaded pools in the tree line and tree-lined road-side ditches, and fully shaded woodland pools. The greatest density of emerging *Ae. atlanticus* was found in the pool at the edge of the woodland study area and the least density was in the woodland pool (Table 5). No *Ae. tormentor* larvae were collected in the field pool. *Ps. ferox* larvae were found in greatest density in the woodland pool.

Dip samples were collected from a total of 20 pools. Three pools were located in the open field, 9 were in the tree-lined road-side ditches and 8 were within the woodland study area. No *Ae. tormentor* larvae were collected in the field pools. Only 1 was collected in the 9 pools with partial shade, and a total of 84 were collected in the 8 pools located in the woodland area (Table 6). Larvae of *Ae. atlanticus* were found in all pools sampled. *Ps ferox* was abundant in fully shaded pools and *Ps. longipalpis* occurred in almost equal density in both partially and fully shaded pools. Both *Ae. fulvus pallens* and *Ae. infirmatus* were most abundant in the woodland pools. The numbers of immatures in the field pools may have been underestimated since a few may have emerged prior to the sampling date of 3 October 1972.

DISCUSSION

Discrete populations of mosquito larvae and pupae in temporary pools present the researcher with a broad spectrum of

Table 5. Numbers of emerging adults of 6 mosquito species collected in 3 stationary emergence traps in 1 pool each for 3 habitats at the Gulf Coast Research Station. Traps were checked daily for 4 days.

	Numbers of emerging adults by pool type		
Species	Field (full sun)	Woodland edge (partial shade)	Woodland (full shade)
Ae. atlanticus	29	82	8
Ae. tormentor	0	7	15
Ps. ferox	7	28	55
Ps. longipalpis	1	4	6
Ps. howardii	4	14	2
Ps. ciliata	0	5	0

sampling variables. Variables not specifically considered in this investigation were predation rates, changes in pool size and differences in individual collector efficiency.

The sampling methods employed were not equal in proportionate numbers of larvae collected by immature stage. It is reasonable to assume that the dipper is most effective at collecting larvae at or near the water surface. In comparison, the area sampler should be equally effective for larvae at all depths, within its depth limitation and should realistically reflect the true numbers of larvae in the sampled area of water. We found that fewer pupae and 4th stage larvae of the *Aedes* species were collected with the dip method than the area sampler. Both methods appeared equally effective in collecting all stages of the *Psorophora* species. This difference might be explained by the field observation that mature larvae, and probably pupae, of the *Aedes* species would more readily sound with slight disturbances. Our findings do not agree with those of Downing (1977) who studied *Ae. canadensis*. This is a subject that warrants additional study.

The natural developmental rates of each species will influence population density estimates if samples are collected daily for several days. Table 7 presents population estimates for the first 5 days after pools A and B were formed in May. It appears that the estimates presented in Table 2 over-estimate population densities for the slower developing species. This is particularly true for populations of *Ae. fulvus pallens*. In fact, the very slow development rate of this species would seem to place it at a biological disadvantage in the Houston area since temporary pools are generally short-lived (Table 1).

Studies of the population distribution of the 6 species demonstrated that the population densities and/or certain behavioral characteristics of *Ps. ferox* and *Ps. longipalpis* larvae resulted in significant, within-pool clumping. Consequently, a greater sampling effort would be required to obtain an estimate of population density with acceptable precision. In comparison, populations of *Aedes* species were randomly distributed and would require less sampling effort to obtain the same precision in population density estimation. The assumption could not be made that species shown to be randomly distributed would retain this distribution at greater population densities. It was shown by Downing (1977) that populations of *Ae. canadensis* were uniformly distributed throughout his study pools. In addition, he reported low population densities of *Ae. canadensis*. It may be that low population densities of larvae, in comparison to those for *Ps. ferox* and *Ps. longipalpis*, are characteristic of some *Aedes* species.

Observations reported on the occurrence of the various species in pools located in field, woodland edge and woodland habitats agree with the habitat preferences demonstrated by the adult populations (Roberts and Scanlon 1975).

Table 6. Numbers of mosquito larvae collected from pools in 3 habitats. Collections were made at the Gulf Coast Research Station, Hitchcock, Texas, 3 Oct. 1972.

Species	Number of mosquito larvae/20-30 dips/pool																			
	Field pools (no shade)			Pools in tree line and tree-lined ditches (partal shade)									Woodland pools (full shade							
	1	2	3	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8
Ae. atlanticus	14	27	6	40	26	27	20	30	50	33	13	18	16	4	19	7	1	9	8	2
Ae. tormentor	0	0	0	0	0	0	0	0	0	0	1	0	10	8	2	9	39	3	2	11
Ps. ferox	0	6	0	1	19	20	9	6	7	4	3	0	18	21	15	31	3	9	15	12
Ps. longipalpis	0	6	0	0	2	1	2	0	0	7	5	1	1	0	1	4	5	1	2	5
Ps. howardii	0	0	0	0	0	0	0	1	0	1	1	0	0	2	0	1	0	1	0	0
Ps. ciliata	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
Ae. fulvus pallens	0	0	0	0	0	0	0	0	0	0	1	5	1	2	2	2	10	5	0	12
Ae. infirmatus	0	0	0	0	0	0	0	0	0	0	0	2	0	2	1	1	0	1	2	0

Table 7. Relative densities of 6 mosquito species in 2 woodland pools at the Gulf Coast Research Station in Hitchcock, Texas. Collections were made during the 1st 5 days after the pools were flooded.

		% of sample population represented by each species									
Month	Pool	*Ae. atl.*	*Ae. torm.*	*Ae. f.p.*	*Ps. ferox*	*Ps. longi*	*Ps. cil.* & *Ps. how.*	Type of sample	Total collected	Number samples collected	Mean per sample
May 72	A	2.5	4.1	7.7	29.5	51.3	4.9	Area	468	35	13.37
May 72	B	9.2	3.9	2.6	44.3	26.8	13.2	Area	228	25	9.12

The significant biological observations on the temporary pool breeders included in these studies were 1) the absence of populations of larvae during mid-winter months for all species (excluding *Ae. infirmatus*); 2) presence of larvae in the study pools at each flooding during the spring, summer and fall months; 3) a developmental time to the pupal stage of 7–8 days for *Ae. atlanticus, Ae. tormentor, Ps. ferox, Ps. longipalpis, Ps. howardii* and *Ps. ciliata*; 4) a prolonged developmental time to the pupal stage (12–15 days) for *Ae. fulvus pallens*; 5) an ability of all species to survive in the pupal stage and emerge from pools without free water; 6) a preponderance of *Ae. tormentor, Ae. fulvus pallens, Ae. infirmatus* and *Ps. ferox* larvae in woodland, fully shaded pools and 7) a more equal distribution of *Ae. atlanticus* and *Ps. longipalpis* larvae in field, ecotone and woodland pools.

Literature Cited

Breland, O.P. 1951. The immature stages of *Aedes infirmatus* Dyar and Knab, with notes on related species. Ann. Entmol. Soc. Amer. 44 (3):362–71.

Carpenter, S.J. and W.J. LaCasse. 1955. Mosquitoes of North America (north of Mexico). University of Calif. Press. 360 pp.

Carpenter, S.J., W.W. Middlekauff and R.W. Chamberlain. 1946. The mosquitoes of the southern United States east of Oklahoma and Texas. The University Press, Notre Dame, Ind. 292 pp.

Dodge, H.R. 1966. Studies on mosquito larvae II. The first-stage larvae of North American Culicidae. Can. Entmol. 98(4):337–93.

Downing, J.D. 1977. A comparison of the distribution of *Aedes canadensis* larvae within woodland pools using the cylindrical sampler and the standard pint dipper. Mosquito News 37(3):362–66.

Gerhardt, R.W. 1966. South Dakota mosquitoes and their control. Bull. S. Dak. Agricul. Exp. Sta. No. 531. 81p. Not seen.

Joule, J.J. and D.L. Jameson. 1972. Experimental manipulation of population density in three sympatric rodents. Ecology 53(4):653–60.

King, W.V., G.H. Bradley, C.N. Smith and W.C. McDuffie. 1960. A handbook of the mosquitoes of the southeastern United States. Agricul. Handbook No. 173. USDA. 188pp.

Remington, R.D. and M.A. Schork. 1970. Statistics with application to the biological and health sciences. Prentice Hall, Inc. 418pp.

Roberts, D.R. 1973. Studies on the biologies of mosquito species incriminated as vectors of Keystone virus in Houston, Texas. Ph.D dissertation. The University of Texas School of Public Health at Houston, Houston, Texas. 130pp.

Roberts, D.R. and J.E. Scanlon. 1974. An area sampler for collecting mosquito larvae in temporary woodland and field pools. Mosquito News 34(4):467–68.

Roberts, D.R. and J.E. Scanlon. 1975. The ecology and behavior of *Aedes atlanticus* D. & K. and other species with reference to Keystone virus in the Houston area, Texas. J. Med. Ent. 12(5):537–46.

Southwood, T.R.E. 1971. Ecological methods with particular reference to the study of insect populations. Chapman and Hall. 391pp.

Travis, B.V. 1969. Arthropods of medical importance in America North of Mexico. U.S. Army Natick Laboratories. Natick, Mass. Tech. Rpt. 69–2–ES. 109pp.