COMPARISON OF FOUR SAMPLING METHODS FOR MEASUREMENT OF *CULEX TARSALIS* ADULT POPULATIONS[1]

R. O. HAYES,[2] R. E. BELLAMY,[3] W. C. REEVES[4] AND M. J. WILLIS[5]

Introduction

Accurate measurements of the abundance of adult mosquitoes are important to the epidemiologist who desires to relate the prevalence of vector species to the incidence of mosquito-borne diseases, and to mosquito control agencies for evaluation of their programs. The usual goal in measurement of mosquito abundance is to determine an effective *index of abundance* above which vector species may be expected to transmit disease or pestiferous species will be of sufficient nuisance to cause serious discomfort to man or domestic animals.

Because of the great diversity of habits of different species of mosquitoes, a method suitable for measuring populations of one species may be unsuitable for another. Currently, a reliable means is needed to measure abundance and fluctuations in numbers of *Culex tarsalis* in the western United States. This mosquito is now recognized as the primary vector of Western equine and St. Louis encephalitis viruses in this area, and extensive programs are being established for its control.

Several methods have been applied to measure the abundance of other important species of mosquitoes in temperate and tropical regions. These methods are generally based on periodic sampling of the general mosquito population by a standardized technique, and subsequent comparison of differences in the numbers collected or counted.

In the course of epidemiological investigations of the encephalitis viruses in Kern County, California, several methods for sampling populations of adult *C. tarsalis* showed promise in preliminary trials. In prior studies, population trends of this species had been obtained by periodic examination of populations in resting shelters or from samples collected by light traps. These methods had permitted the recognition of gross seasonal fluctuations in the abundance of the species; however, a comparative evaluation of several sampling methods was needed. Four promising methods of measuring populations of adult *C. tarsalis* were selected for comparison by concurrent testing in selected areas of Kern County.

The study was made in three field areas all within a 35-mile radius of Bakersfield and suitable for epidemiological investigations of the arthropod-borne virus encephalitides. Each area differed from the others in characteristic flora and fauna, but all had large mosquito populations, particularly of *C. tarsalis*. The specific study areas were: Jerry Slough, an area of intensively irrigated cropland largely surrounded by desert; Arkelo Olive Grove, a large olive grove in irrigated agricultural land; and Hart Park, a wooded recreational park along the Kern River.

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[2] Technology Branch, Communicable Disease Center, P. O. Box 1564, Bakersfield, California. Currently assigned to Taunton Field Station, P. O. Box 631, Taunton, Massachusetts.

[3] Technology Branch, Communicable Disease Center, P. O. Box 1564, Bakersfield, California.

[4] School of Public Health, University of California, Berkeley.

[5] Epidemiology Branch, Communicable Disease Center, Atlanta, Georgia.

SAMPLING PROCEDURES

The four methods of sampling populations of adult mosquitoes selected for comparison were collection of specimens by:

1. Aspirator in "Natural Shelters."
2. Aspirator in "Artificial Shelters."
3. New Jersey and American Mosquito Light Traps.
4. Dry Ice (carbon dioxide) Baited Mosquito Traps.

1. Natural Shelters. Mosquitoes were known to come to rest during the day at all the natural stations selected, which included porches, garages, sheds, areas under bridges and houses, and hollows and irregularities at tree bases. In some instances the "station" was a specified portion of a shelter. Once a week all the mosquitoes were collected from each station, which were distributed as follows: 13 in Jerry Slough, 8 in Hart Park and 2 (each consisting of a row of 10 trees) in Arkelo Olive Grove.

2. Artificial Shelters. Cubical reinforced plywood boxes of one cubic foot capacity were enameled red inside and out, approximately the unit described by Goodwin (1942). The boxes were located on the ground at tree bases, a river bank, pastures, an alfalfa field, and even within natural shelters, such as garages and under buildings. In each collecting area, the boxes which consistently attracted the largest number of mosquitoes were retained; others were removed. Once a week each box was visited, and all the mosquitoes that could be collected from it by aspirator composed the station collection. From 5 to 8 box stations were used at Jerry Slough and 5 or less in the other two areas.

3. Light Traps. New Jersey and American type light traps (Mulhern, 1953) were used with a 25-watt bulb frosted white inside. The traps were started automatically or manually at least an hour before sunset and were run until the following morning, when the collector removed the cloth collecting cage which substituted for the usual cyanide jar. Light traps were operated at 4 stations in Jerry Slough and at one station in each of the other areas.

4. Bait Traps. Portable lard can bait traps (Bellamy and Reeves, 1952) were operated with dry ice (CO_2) bait. The standard bait was a rectangular block of dry ice weighing about 2.5 pounds, wrapped in a double layer of 50 weight Kraft paper, and closed securely with strips of two-inch-wide 60 weight gum paper tape. At the time a trap was baited, usually in the afternoon, approximately one-half inch openings were cut in four sides of the wrapping to permit escape of the CO_2 gas. Some dry ice usually remained in the trap the following morning unless it had been exposed to excess afternoon sun or unusually high night temperatures. In the morning, before transporting the traps to the laboratory, the trap openings were plugged with cotton to prevent the escape of trapped mosquitoes. The traps were operated in a horizontal position in a variety of places, such as on the ground, in tree crotches, and on top of buildings. Some bait trap stations which were not productive were abandoned and new stations were selected. Traps were generally operated at 4 stations in Jerry Slough and at 2 to 6 stations at Hart Park and Arkelo Olive Grove.

COLLECTING SCHEDULE

For all four collecting methods, once established, a station remained the same throughout the major part of the study, with exceptions as noted. Insofar as possible, from June 1, 1953, through June 30, 1954, light trap collections and those from natural and artificial shelters were made regularly in the three study areas, one collection at each station every week. Bait trap stations were selected in the late summer 1953, and bait traps were operated more or less regularly until winter (December to March, inclusive), when the traps were operated irregularly about once each month. Beginning in April 1954 they were operated once each week.

In some studies, a time limit factor has been used to standardize mosquito collections at stations, e.g., a collection would consist of all mosquitoes that could be captured in ten minutes. In this study the time limit concept was never employed; instead, thoroughness was stressed, the objective being a complete collection of all specimens at an artificial or natural shelter. If possible the collections were made at the same time of day at specific stations each week. To avoid unfavorable effects of high summer temperatures, collection from shelters was begun early enough in the morning to permit completion of the day's collections by noon.

STATISTICAL ANALYSES

Two principal methods of analysis were selected following a number of preliminary analyses and graphic considerations of raw data.

First, weekly arithmetic mean numbers of specimens were determined for each method of collection in each study area. For example, for a given week the total number of female *C. tarsalis* collected by light traps at Jerry Slough was divided by the number of light trap collections made in Jerry Slough during that week. A similar calculation was made for males. The weekly means were converted to biweekly means by taking half the sum of the means of two consecutive weeks. Averages for periods greater than two weeks were undesirable, as seasonal population trends would be obscured.

Second, the biweekly means, obtained as indicated above, for each collecting method at each study area, were ranked according to magnitude, and Spearman's method of rank correlation (Snedecor, 1946) was utilized in making comparisons. By this method it was possible to compare the year-around population trends as measured by the different collecting methods, or by a single collecting method in different study areas. It was also possible to compare the results from a single collecting method at replicate stations within a study area by this procedure.

In performing Spearman's correlation, the biweekly means for any given collecting method at any study area were ranked: the largest biweekly mean for the period of the study was given the highest rank and the smallest biweekly mean the lowest; the others according to magnitude were ranked between. Spearman's formula, $r = 1 - \frac{6 \Sigma d^2}{n(n^2 - 1)}$ was utilized in making the rank correlations. The standard deviation of the rank correlation is $\frac{1}{\sqrt{N-1}}$.

RESULTS

The biweekly means of female *C. tarsalis* collected by each of the four sampling methods in the three study areas are shown in Table 1 and Figure 1. The size of samples varied widely in magnitude, but regardless of the method of sampling or area studied, there was a striking similarity in population trends. The population exhibited a marked increase in late spring and built up to a summer peak which was then followed by a distinct autumn decline. In the winter, results from the several sampling methods diverged widely. Natural shelter collections in the Jerry Slough and Hart Park areas yielded comparatively large samples, and there was even an apparent increase in the shelter population at Hart Park. Only small numbers of specimens were taken in collections by light traps and bait traps and from artificial shelter units. Adult female *tarsalis* were taken in light trap collections and from artificial shelters in each winter month, but in only small numbers from December through March. Bait traps produced still fewer specimens in the winter season, none in December or March, but bait traps were operated infrequently during the winter. The winter population of female *C. tarsalis* in Arkelo Olive Grove was minimal; specimens were collected each month but in small num-

Fig. 1.

AVERAGE NUMBER OF *Culex tarsalis* FEMALES COLLECTED DURING TWO WEEK PERIODS IN THREE STUDY AREAS OF KERN COUNTY BY FOUR SAMPLING METHODS

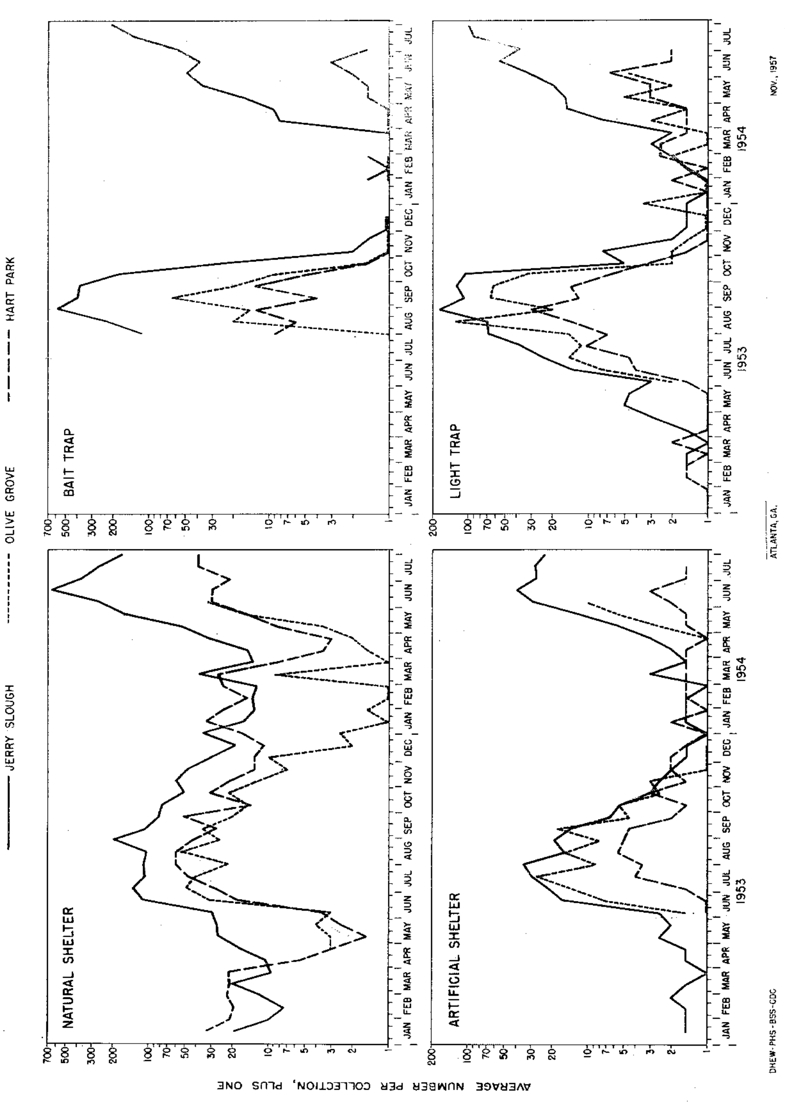

TABLE 1.—Average number of *Culex tarsalis* females collected during two-week periods in three study areas of Kern County by four sampling methods

Inclusive Dates	Jerry Slough				Olive Grove				Hart Park			
1953–54	NS	AS	LT	BT	NS	AS	LT	BT	NS	AS	LT	BT
Jan. 8–21	18.5	0.5	–	–	–	–	–	–	32.0	–	0.0	–
Jan. 22-Feb. 4	9.0	0.5	–	–	–	–	–	–	20.0	–	0.0	–
Feb. 5–18	6.5	0.5	–	–	–	–	–	–	18.5	–	0.5	–
Feb. 19-Mar. 4	11.0	1.0	0.5	–	–	–	–	–	21.0	–	0.5	–
Mar. 5–18	19.5	0.5	0.5	–	–	–	–	–	20.0	–	0.0	–
Mar. 19-Apr. 1	8.5	0.0**	0.0	–	–	–	–	–	20.5	–	1.0	–
Apr. 2–15	9.5	0.5	0.5	–	–	–	–	–	4.5	–	0.0	–
Apr. 16–29	16.5	0.5	2.0	–	2.0	–	–	–	2.0	–	0.0	–
Apr. 30-May 14	25.5	1.5	4.0	–	2.0	–	–	–	0.5	–	0.0	–
May 15–28	26.0	1.0	3.5	–	3.0	–	–	–	1.5	–	0.0	–
May 29-June 11	28.5	1.5	2.0	–	2.0	0.5	1.0	–	2.5	0.0**	0.5	–
June 12–25	112.0	15.0	13.0	–	30.0	6.0	7.0	–	17.0	0.0	3.0	–
June 26-July 9	133.0	20.0	23.5	–	47.5	12.5	13.5	–	27.0	0.5	3.5	–
July 10–23	107.5	28.0	37.5	–	39.5	25.5	10.5	–	45.0	3.0	9.5	–
July 24-Aug. 6	109.0	33.0	67.5	114.5	20.5	7.5	13.5	0.0	57.5	2.5	6.0	8.0
Aug. 7–20	102.5	14.5	68.5	228.5	53.0	14.5	127.5	19.0	57.5	4.5	13.0	5.0
Aug. 21-Sept. 3	194.0	18.0	173.5	579.5	24.5	7.0	19.0	13.5	41.5	4.0	29.0	12.0
Sept. 4–17	108.0	13.0	109.0	395.5	33.5	16.5	63.5	62.5	26.0	3.5	11.0	3.0
Sept. 18-Oct. 1	82.5	5.5	125.0	378.0	19.0	3.5	61.0	19.0	50.5	1.0	13.0	12.0
Oct. 2–15	76.5	4.5	105.0	179.0	14.0	4.5	31.0	8.0	13.0	0.5	5.5	4.0
Oct. 16–29	49.5	2.0	4.0	20.5	20.5	1.5	1.0	0.5	30.0	2.0	2.0	0.5
Oct. 30-Nov. 12	58.0	1.5	6.5	1.0	11.5	2.0	1.0	0.0	25.0	0.5	0.5	0.0**
Nov. 13–26	45.5	1.0	1.0	0.5	6.0	0.0**	0.5	0.0	12.0	1.0	0.0	0.0
Nov. 27-Dec. 10	29.5	0.5	0.5	0.0	9.0	0.0	0.0	0.0	12.0	1.0	0.0	0.0
Dec. 11–24	18.0	0.5	0.5	0.0	1.0	0.0	0.0	0.0	10.0	0.5	0.0	0.0
Dec. 25-Jan. 7	35.0	0.0	0.5	–	1.5	–	2.5	–	15.5	0.0**	0.0	–
Jan. 9–21	15.0	0.5	0.0**	–	0.0	–	0.0	–	32.0	1.0	0.0	–
Jan. 22-Feb. 2	12.0	0.5	0.0	0.5	0.5	–	0.0	0.0	22.5	0.0**	1.0	0.0
Feb. 5–18	12.5	0.5	0.5	0.0	0.0	–	0.5	0.0	14.0	0.5	0.0	0.0
Feb. 19-Mar. 4	11.5	0.0	1.0	0.5	0.0	–	1.0	0.0	23.0	0.5	1.5	0.0
Mar. 5–18	37.0	2.0	2.0	–	8.0	–	0.0	–	25.5	0.5	1.5	–
Mar. 19-Apr. 1	12.5	0.5	1.0	0.0	0.0	–	0.0	0.0	7.5	0.5	0.5	0.0
Apr. 2–15	14.0	1.0	6.5	7.0	0.5	–	2.0	0.0	2.5	0.5	0.5	0.0**
Apr. 16–29	30.5	2.0	14.0	8.0	1.0	0.0	0.5	0.0	2.0	0.0	0.5	0.0
Apr. 30-May 13	52.5	4.5	14.5	15.0	2.5	1.5	4.0	0.0**	7.5	0.5	2.0	0.5
May 14–27	161.0	11.0	18.5	34.5	14.0	4.5	1.0	0.0	14.0	0.5	2.0	0.5
May 28-June 10	262.5	27.5	30.0	47.5	31.0	9.0	3.5	0.0**	29.0	1.0	5.5	1.0
June 11–24	643.0	38.0	53.5	35.5	–	–	–	–	28.5	2.0	1.0	2.0
June 25-July 8	362.0	26.0	36.0	57.0	–	–	–	–	20.0	0.5	1.0	0.5
July 9–22	258.0	26.5	87.0	132.0	–	–	–	–	37.0	0.5	–	–

Inclusive Dates 1953–54	Jerry Slough NS	Jerry Slough AS	Jerry Slough LT	Jerry Slough BT	Olive Grove NS	Olive Grove AS	Olive Grove LT	Olive Grove BT	Hart Park NS	Hart Park AS	Hart Park LT	Hart Park BT
Jan. 8–21	0.0**	0.0	–	–	–	–	–	–	0.0	–	0.0	–
Jan. 22-Feb. 4	0.0	0.0	–	–	–	–	–	–	0.0	–	0.0	–
Feb. 5–18	0.0	0.0	–	–	–	–	–	–	0.0	–	0.0	–
Feb. 19-Mar. 4	0.0	0.0	0.0	–	–	–	–	–	0.0	–	0.0	–
Mar. 5–18	0.0	0.0	0.0	–	–	–	–	–	0.0	–	0.0	–
Mar. 19-Apr. 1	0.0**	0.0	0.0**	–	–	–	–	–	0.0**	–	0.0	–
Apr. 2–15	3.0	0.0	0.0	–	–	–	–	–	0.5	–	0.0	–
Apr. 16–29	4.0	0.5	1.0	–	1.5	–	–	–	0.5	–	0.0	–
Apr. 30-May 14	10.0	1.0	0.0	–	1.0	–	–	–	1.0	–	1.0	–
May 15–28	7.0	1.5	0.5	–	1.5	–	–	–	1.0	–	0.5	–
May 29-June 11	5.0	1.0	0.5	–	1.0	0.0	0.0	–	2.0	0.0	0.0	–
June 12–25	17.5	5.0	3.5	–	6.0	3.0	0.0	–	4.0	0.0	0.0	–
June 26-July 9	30.0	6.0	3.5	–	22.5	5.5	13.0	–	11.0	1.0	0.0	–
July 10–23	15.5	4.5	4.0	–	11.0	10.5	4.0	–	16.0	2.0	3.0	–
July 24-Aug. 6	11.5	3.5	1.5	0.5	9.0	2.5	16.0	0.0	9.0	2.0	3.0	0.0
Aug. 7–20	9.0	1.0	2.0	0.0	21.5	6.0	89.0	0.0	8.0	1.5	2.5	0.0
Aug. 21-Sept. 3	21.5	3.0	8.0	0.0**	22.5	8.5	8.0	0.0	12.5	2.0	2.5	0.0
Sept. 4–17	23.0	5.5	13.0	0.0	30.0	20.0	28.5	1.0	14.5	2.0	5.5	0.0
Sept. 18-Oct. 1	25.5	2.5	9.0	0.0	37.0	11.0	26.0	1.5	35.5	0.5	4.5	0.0
Oct. 2–15	46.0	4.0	25.0	0.0	25.0	10.0	44.5	1.0	26.5	1.5	11.0	0.5
Oct. 16–29	41.0	2.5	19.5	0.0**	28.0	2.5	31.0	0.0	35.5	0.5	11.0	0.0**
Oct. 30-Nov. 12	38.5	2.0	48.0	0.0**	8.5	2.0	6.5	0.0	35.0	0.5	8.0	0.5
Nov. 13–26	22.5	0.5	5.0	0.0	1.5	0.5	0.0	0.0	9.0	0.0**	1.0	0.0**
Nov. 27-Dec. 10	4.5	0.0	1.5	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
Dec. 11–24	0.0**	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0**	0.0	0.0	0.0
Dec. 25-Jan. 7	0.0	0.0	0.0	–	0.0	–	0.0	–	0.0	0.0	0.0	–
Jan. 8–21	0.0	0.0	0.0	–	0.0	–	0.0	–	0.0	0.0	0.0	–
Jan. 22-Feb. 4	0.0	0.0	0.0	0.0	0.0	–	0.0	0.0	0.0	0.0	0.0	0.0
Feb. 5–18	0.0	0.0	0.0	0.0	0.0	–	0.0	0.0	0.0	0.0	0.0	0.0
Feb. 19-Mar. 4	0.0	0.0	0.0	0.0	0.0	–	0.0	0.0	0.0	0.0	0.0	0.0
Mar. 5–18	0.0**	0.0	0.0	–	0.0	–	0.0	–	0.0	0.0	0.0	–
Mar. 19-Apr. 1	0.5	0.0**	0.5	0.0	0.0	–	0.0	0.0	0.0	0.0	0.0	0.0
Apr. 2–15	5.0	0.5	0.0**	0.0	0.0	–	0.5	0.0	0.5	0.0	0.0	0.0**
Apr. 16–29	13.5	1.5	3.0	0.0	1.5	0.0	0.0	0.0	1.0	0.5	0.0	0.0
Apr. 30-May 13	16.5	2.5	3.5	0.0	2.0	0.5	2.0	0.0	4.0	0.0**	0.0	0.0
May 14–27	70.5	7.0	6.0	0.0	3.0	2.5	1.5	0.0	8.5	0.0**	1.5	0.0
May 28-June 10	151.5	21.5	17.0	0.0**	10.0	3.0	2.5	0.0	12.5	0.5	0.5	0.0
June 11–24	553.0	42.5	66.0	0.5	–	–	–	–	11.0	1.0	0.0	0.0
June 25-July 8	192.0	20.0	17.0	0.0	–	–	–	–	4.5	0.5	0.0	0.0
July 9–22	23.0	8.5	9.5	0.0	–	–	–	–	9.0	0.5	–	–
July 23-Aug. 5	25.5	6.0	23.5	0.0	–	–	–	–	7.0	–	–	–

** Mosquitoes collected but average less than 0.25.

bers and not consistently by any method.

The biweekly mean number of male *C. tarsalis* collected in the Jerry Slough study area by the four sampling methods are shown in Table 2. Only occasional males were taken in bait traps. In each study area, males reappeared in natural shelters prior to the major spring population increase of females. Results from the various sampling methods (except those from bait traps) at each study area, indicate a parallel springtime upward trend of the female and male populations. In both winters of the study, 1952–53 and 1953–54, males were almost wholly absent from collections from late December to early March. In the spring, males were detected most consistently in collections from natural shelters, and were taken irregularly and in small numbers at light traps and artificial shelters.

Table 3 gives the rank correlation coefficients for 18 intra-area and 12 inter-area comparisons for females and 9 of each type comparison for males. Two types of comparison are made. The intra-area correlation coefficients show the strength of agreement between different sampling methods in depicting the year around population trends within a single study area, and the inter-area correlation coefficients are similar measures of agreement of results from a single sampling method in two different study areas. Bait trap collections of males are excluded from these comparisons since males are seldom taken in bait traps.

TABLE 3.—Intra-area and inter-area rank correlation coefficients for two-week *Culex tarsalis* collection averages. (female above diagonal x entries, male below)

		Jerry Slough Area				Olive Grove Area				Hart Park Area			
		NS	AS	LT	BT	NS	AS	LT	BT	NS	AS	LT	BT
Jerry Slough Area	NS	x	.87	.82	.70	(.91)	–	–	–	(.96)	–	–	–
	AS	.93	x	.86	.80	–	(.87)	–	–	–	(.45)	–	–
	LT	.81	.73	x	.96	–	–	(.88)	–	–	–	(.78)	–
	BT	*	*	*	x	–	–	–	(.83)	–	–	–	(.95)
Olive Grove Area	NS	(.85)	–	–	–	x	.91	.74	.76	(.57)	–	–	–
	AS	–	(.63)	–	–	.89	x	.78	.67	–	(.55)	–	–
	LT	–	–	(.70)	–	.87	.72	x	.82	–	–	(.83)	–
	BT	–	–	–	(*)	*	*	*	x	–	–	–	(.84)
Hart Park Area	NS	(.91)	–	–	–	(.92)	–	–	–	x	.69	.60	.71
	AS	–	(.72)	–	–	–	(.73)	–	–	.81	x	.51	.72
	LT	–	–	(.65)	–	–	–	(.83)	–	.80	.75	x	.89
	BT	–	–	–	(*)	–	–	–	(*)	*	*	*	x

NS—Natural Shelter
AS—Artificial Shelter.
LT—Light Trap.
BT—Bait Trap.
*—No comparison; insufficient numbers collected for ranking.
Coefficients in parentheses are inter-area comparisons.
All coefficients in this table show significantly positive correlation at the 5 percent probability level or less.

The minimum number of paired ranks used in preparing Table 3 was 15. The maximum value of the standard deviation equals 0.267. All intra-area and inter-area comparisons showed significantly positive correlation coefficients at the five percent probability level. Increases and decreases in the ranks of biweekly means from one method of collection were usually accompanied within a given study area by similar changes in the ranks of the biweekly means from the other methods of collection. For a single collecting method, the ranking of the biweekly means tended to show the same trends in different study areas. The exceptions were so infrequent that they did not destroy the significance of the correlation. The comparatively large numbers of specimens in the winter natural shelter collections from Hart Park affected the rankings from that area, but the correlation is still at the significant level (Table 3).

A further test was made of the agreement between the results from one collecting method at different collecting stations in the same study area. Data from Jerry Slough natural shelter stations which differed widely in the average number of mosquitoes present were selected for comparison by rank correlation. These were designated station 1 (best), station 2 (good), station 3 (fair), and station 4 (worst), in order of decreasing numbers of specimens found. Collections from each station were ranked and compared. The rank correlation coefficients are presented in Table 4. For each coefficient, the number of pairs compared was 30, so the standard deviation of the coefficient equals 0.186. At the five percent probability level, all coefficients were significantly positive except those involving the "worst" station which yielded irregular and small number samples.

Similar comparisons were made using the data on males and females from the four light trap stations and from four of the eight artificial shelter stations at Jerry Slough. Data on females from the four bait trap stations in Jerry Slough were similarly ranked and compared. In all cases significantly positive correlations were obtained, but the detailed results are not presented because of their similarity to the previous example.

No emphasis was placed on the determination of population trends of the other species of mosquitoes collected by the several sampling methods, but the following general observations were made:

Culiseta inornata was most abundant during the fall and winter and was the only species, other than *C. tarsalis,* taken at light traps during January and February. *C. inornata* was not collected in August. *Culex quinquefasciatus* was found in natural and artificial shelters in increasing numbers through summer and fall, and was taken infrequently and in only small numbers in late winter and spring. During October and November of 1953, *C. quinquefasciatus* was the principal species taken in bait traps. *Culex stigmatosoma* was found in greater abundance in collections from natural shelters than in other collections. Its population reached a peak in July and August.

TABLE 4.—Rank correlation coefficients for selected natural shelter stations in the Jerry Slough area based on two-week female and male *Culex tarsalis* collection averages

Station		Station No. 2 (Good)	Station No. 3 (Fair)	Station No. 4 (Worst)
Station No. 1	Female	.53	.73	.21
(Best)	Male	.86	.82	.52
Station No. 2	Female	–	.61	.03
(Good)	Male	–	.76	.48
Station No. 3	Female	–	–	.30
(Fair)	Male	–	–	.66

Values greater than 0.37 represent significantly positive correlation at 5 percent probability level.

The largest populations of *Aedes nigromaculis* and *A. melanimon* occurred at Jerry Slough, and the largest numbers of specimens were taken in light trap collections. As measured by light trap collections at Jerry Slough, small populations of these species took wing in late April and May, and there were noticeable waves of increasing abundance through the summer, climaxing in the largest populations in late August and early September, with the populations receding rapidly in October and early November. *Anopheles freeborni* and *A. franciscanus* were most commonly collected in shelters or by light trap but were never abundant.

DISCUSSION

Comparison of four collecting methods in three different study areas minimized the chance that characteristics peculiar to a single study area would lead to misevaluation and increased confidence in the general applicability of the findings. The positive relationships noted by rank correlation coefficient evaluation between areas and between all collecting methods substantiate the value of the sampling procedures for measuring adult *C. tarsalis* populations. Comparison of samples collected by each sampling method at replicate stations in a small area indicates that any single well selected station will provide a representative measure of annual population trends.

Some of the observed merits and limitations of the different sampling methods are:

NATURAL SHELTER: Merits. 1. If good stations are selected, the natural shelter unit provides the largest collections and is the most sensitive unit on a year around basis.

2. Presumably, collections from natural shelters are the most nearly representative cross-section of the adult population, i.e., all fractions of the population are represented: males, females with blood, gravid females, freshly emerged specimens, etc.

Limitations. 1. It is essentially impossible to standardize collections from natural shelters for comparison with results in other geographic areas, because natural shelter units are so variable in size, shape, and permanence.

2. A station which is sensitive enough to be positive at the time of minimal populations may well provide so many specimens at the time of peak population that collecting and identifying the specimens is a real burden.

3. Some units are attractive to mosquitoes at one season but less attractive at another.

ARTIFICIAL SHELTER: Merits. 1. As in natural shelters the general population is sampled, although in smaller numbers, on a year around basis.

2. The artificial shelter is a standard unit in dimensions, therefore comparisons between units have more validity than for natural shelters.

3. These units are readily portable and non-mechanical and they can be placed where there are no suitable natural shelters.

Limitations. 1. Insufficient numbers of specimens may be attracted to some units; the sensitivity of good natural shelters is not provided.

2. Some experience in placing units at suitable locations is necessary and poor choice of location will result in unsatisfactory stations.

LIGHT TRAP: Merits. 1. The unit is widely utilized by mosquito control agencies as a standard. This permits comparisons, with some limitations, between geographic areas.

2. There is minimal chance of an environment being changed so this unit cannot be operated, thus comparisons can be made with recorded results for previous years at a specific location.

3. Both male and female *C. tarsalis* are attracted.

Limitations. 1. Collections are difficult to handle and require much sorting of miscellaneous insects.

2. The ordinary unit can be operated only where a suitable source of power is available.

3. Power failures or mechanical trap failures may occur.

4. Freshly engorged and gravid females are not adequately sampled.

CARBON DIOXIDE BAIT TRAP: Merits. 1. The (presumably) blood-seeking fraction of the female population is attracted.

2. Collections are free of other insects, debris, etc., and are therefore easy to handle.

3. The unit can be standardized easily.

4. The unit can be placed in any location and is not subject to mechanical failure.

Limitations. 1. There is no measure of the male or engorged and gravid female portion of the population.

2. The unit is not attractive to mosquitoes in cold weather.

3. The bait must be placed in the unit each night it is to be run.

From the above critique of the several collecting methods, it is obvious that one method may serve one purpose best but may be ineffective for another. Thus, the epidemiologist will probably be most vitally interested in the vector attack rate and, of the above methods, the dry ice baited trap is the method of choice. On the other hand, a mosquito control agency may be concerned with the numbers of male specimens both as an indication of proximity to breeding areas and as a sign of recent emergence. In this case, the bait traps are not the answer. Either shelter collections or light trap collections are indicated, with the light traps providing a somewhat greater chance than the shelters of being maintained without alteration. The entomologist may wish to maintain as complete a picture as possible of the population. If so, he will obtain important data from all four methods. For a single method, the shelter collections probably would give the most complete data.

It is important that stations be chosen carefully. This has been noticed particularly in placing the red box artificial shelter units. In a number of instances these have been placed where few mosquitoes were attracted, while at a nearby location an identical unit would attract many more specimens. It is recommended that in placing such units for preliminary trials, three or four boxes be installed at a location where it is desired to locate one permanently. After a number of observations, one unit may be seen to attract many more mosquitoes than the others. This best unit can be used as the permanent station and the others discontinued.

In this study, the populations in the three study areas were undoubtedly affected to some degree by mosquito control measures. No attempt was made to measure the effect of mosquito control activities on the *C. tarsalis* population.

SUMMARY

Four methods of collecting adult *Culex tarsalis* were compared through a period of more than a year at three localities in Kern County, California. The collections were made by: aspirator in natural shelters, aspirator in one-cubic-foot red box artificial shelters, mosquito light traps, and dry ice (CO_2) baited traps.

All methods proved satisfactory for measuring the abundance of adult female *C. tarsalis* in the summer. All methods except bait traps adequately sampled male *C. tarsalis*. There was close agreement between the population trends indicated by the different collecting methods within single areas and by each collecting method in the three localities.

Each of the four sampling methods has advantages and limitations for *C. tarsalis* population measurement depending on whether the application is to mosquito control, epidemiological or biological studies.

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