ARTICLES

INVESTIGATIONS OF A RECURRENT FLIGHT PATTERN OF FLOOD WATER *AEDES* MOSQUITOES IN KERN COUNTY, CALIFORNIA [1]

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For a considerable number of years the northern portion of the urban area of Bakersfield, California has been invaded periodically during the summer months by flood water *Aedes* mosquitoes from unknown sources. The only early reference to this problem in the district files is a letter dated in 1938 to the University of California. This letter described periodic flights of *Aedes* mosquitoes into the Bakersfield area and requested aid in determining their origin. Limited investigations were conducted by the University without results.

During the period 1946 through 1952 these flights became progressively heavier, reaching a point where the residents of the affected area were subjected to very heavy biting rates during the daylight hours and were unable to carry on their customary outside activities with any degree of comfort. In August and September of 1949, flights moved into the affected area in much heavier numbers than had been previously experienced. Service requests exceeded 100 per day during the peak periods.

Prior to this time no concentrated effort had been directed toward locating the source of the invading mosquitoes. By this time it became plainly evident that the situation was not being abated through normal district activities and that flights were originating either at a source as yet unsuspected within the district or coming from outside the district boundary. During the latter part of the 1949 season, intensive special inspections within the district boundaries failed to turn up any possible source. By the end of the 1949 season it was apparent that a special study would be necessary to locate the source of these mosquitoes.

In examining the known facts prior to beginning the study, several things were apparent:

1. The north edge of the urban area of Bakersfield lies eight miles from the nearest district boundary across dry foothills. Although considerable numbers of *Aedes* could be found in the foothills north to and beyond the district line during the flight periods, no source could be found in this area.
2. The invasions followed a rather definite pattern as shown by the rise and fall in numbers of service requests due to *Aedes* mosquitoes over a period of time. They occurred principally during the period from June 1 through September 30.
3. The frequency of the flights increased with the temperature. They were from about 10 to 14 days apart during the cooler part of the summer, and about 5 days apart during the hottest season in August and early September.
4. The flights were characterized by a sudden influx of mosquitoes, reaching an immediate peak and dropping off over a period of several days. The pattern appeared to be that of a frontal movement.

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Urban Bakersfield encroaches to the north on a foothill area running roughly east and west. These foothills swing to a north-south direction west of the urban area. The flights struck this foothill area first, and, if intensity was high, gradually filtered into the northern part of the lower areas of the city.

The major species involved was *Aedes nigromaculis* although some *Aedes dorsalis* were captured during the flights. *Aedes nigromaculis* is not a native California species. It was first taken in 1938 in the northeast portion of the state, but has since become the primary flood water *Aedes* associated with irrigated agriculture. Instead of one generation a year in river overflow lands, one generation is produced with each irrigation, in some areas 15 to 20 generations per year, developing in tremendous numbers during the latter part of the season.

It seemed very unlikely that a single source of *Aedes* of sufficient size to produce the numbers of mosquitoes involved in these flights could be present but unknown within the confines of the district. The periodicity of the flights was, however, indicative of an irrigation cycle, so another intensive field search was made in the district to the north and northwest of the city. At the same time, an aerial survey was made of the dry foothill area north of the city for a distance of 30 miles to determine whether or not there were any irrigation operations in that area which might serve as sources of the flights. Both of these searches resulted in negative findings. Poso Creek, a small stream north of the city running through the foothills from east to west, was considered a possible source for a time. *Aedes* adults were found in considerable numbers in the green growth along the stream banks during flight periods. During the summer the water in this stream is entirely derived from oilfield operations and the flow was found to fluctuate considerably. Continued inspection of this stream failed to turn up any *Aedes* larvae or any indication of recent emergences during the flights.

During this early period, attempts were made also to trace back to the source by checking biting rates over a wide area in the valley and foothills. It was found that the heaviest biting rates were in the northern foothill fringe of the city. Second heaviest biting was found in isolated areas of green vegetation in the foothills proper, and the lightest biting was in the irrigated area adjacent to the foothills. This dry foothill area, which would seem to be the last place to expect to find *Aedes* mosquitoes, was found to be much more extensively invaded than had been expected. Rather than being on the margin of the affected area, it now appeared to be the principal area hit by the flights. The mosquitoes were also found in the lower reaches of the Tehachapi Pass to the east as far as Keene, approximately 28 miles southwest of Bakersfield.

In order to check for correlation of *Aedes* mosquito population throughout this area, light traps were established at Woody, approximately 27 miles north, northeast of the city, and at Keene. Body count stations were also established through the foothill area north of Bakersfield. These stations lay in a north-south line, paralleling the east side of the valley and from 8 to 10 miles into the foothills, extending to a point 14 miles north of Bakersfield. These stations were visited daily for three years during the mosquito season. In addition to these routine counts, random sampling was carried out throughout the foothill area in order to fill in between the stations and to better assess the area affected. Presence and population density fluctuations correlated throughout this area, with the greatest variation in time of appearance of the flights being 24 hours, progressing from northwest to southeast. (Fig. 1).

Further attempts to define accurately the area of invasion were not made due to lack of time and personnel. It was not felt that complete definition of this area was necessary to the solution of the problem.

Early in the investigation it became apparent that the invaded area was so large and the numbers of mosquitoes present

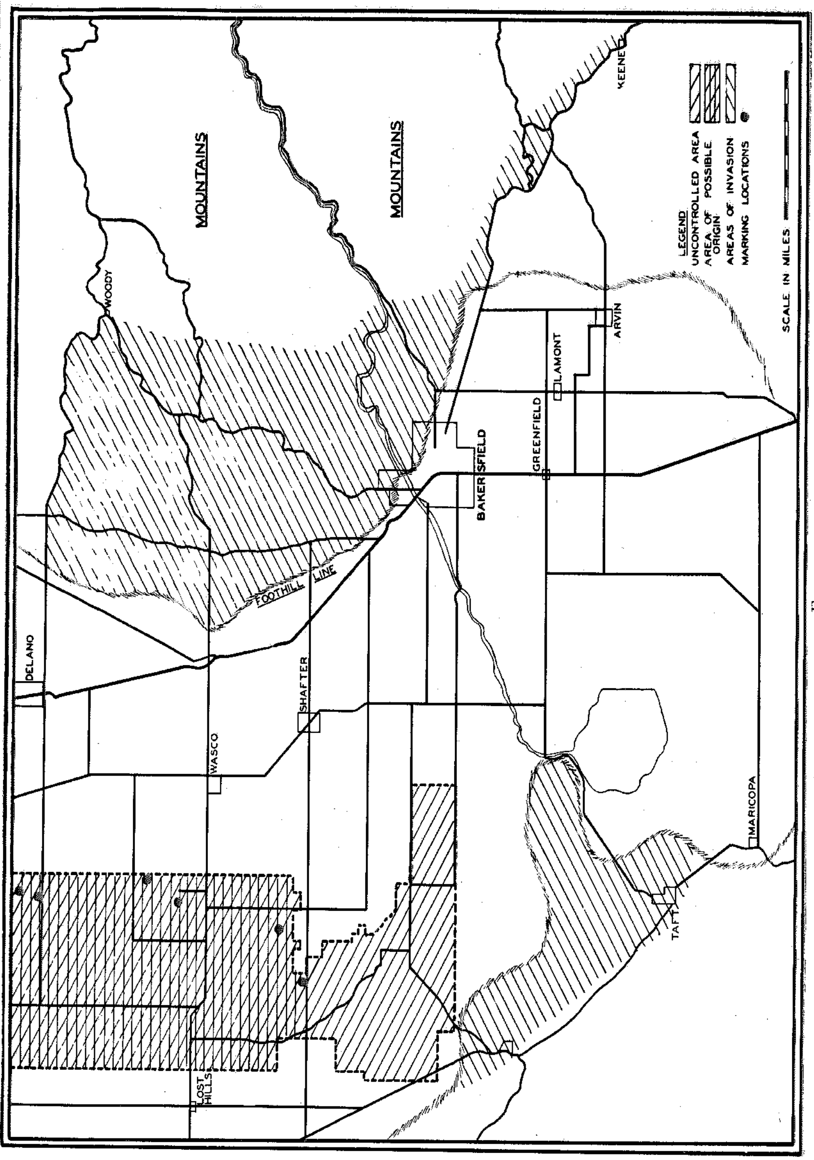
MOUNTAINS
MOUNTAINS
WOODY
KEENE
LEGEND
UNCONTROLLED AREA
AREA OF POSSIBLE ORIGIN
AREAS OF INVASION
MARKING LOCATIONS
SCALE IN MILES
ARVIN
LAMONT
GREENFIELD
BAKERSFIELD
FOOTHILL LINE
DELANO
SHAFTER
WASCO
MARICOPA
TAFT
LOST HILLS

FIG. 1

were such that if a single source was responsible, it must be of very considerable magnitude. The other possibility was that the mosquitoes were moving from an area with enough individual sources to build up a high adult population density, and that mass migrations from this area were set off by some natural phenomenon. Since no single large source could be located which might account for the pattern presented, consideration was turned to the other possibility.

Following the 1950 season, daily records of temperature, barometric pressure, relative humidity and wind direction and speed were obtained for the years 1949 and 1950 from the weather bureau station at Bakersfield. These data were broken down in various ways and plotted against the flight periods for these two years. The graphs were taken to the weather bureau for examination and analysis by the meteorologist. He found what he considered an excellent correlation between a recurrent meteorological pattern and the flight periods. The pattern consisted of a barometric gradient from the coastal area to the west into the valley. When this gradient occurs, cool air is drawn from the coast into the valley through a low area in the hills bordering the west side of the valley and striking primarily in the Lost Hills—Semi Tropic area on the west side of the valley. The effects of this gradient are three-fold. First, the cool coastal air moving down the gradient reduces the valley temperature several degrees. Second, the influx of air from the west moves the existing air mass in the valley easterly toward the foothills along the east side of the valley. Third, the cool air striking the hot valley floor sets up a very strong thermal updraft in the Lost Hills—Semi Tropic area.

A large part of the area first touched by this air mass is not in any mosquito abatement district. The land use pattern is one of scattered farms, most of which either border on or are close to undeveloped land. Excess irrigation water is wasted off onto this unused land, causing reflooding of the low areas with each irrigation and setting up very favorable conditions for flood water *Aedes*.

Since this meteorological pattern correlated with the flights over a period of time and the associated air mass movement struck an area of high *Aedes* breeding potential, this area was strongly indicated as the source of the flights. On the basis of the air movements set up by the invasion of the valley by this cool air mass, it could be hypothesized that the movement could take place in one or both of two ways.

First, a movement along the valley floor into the foothills with the displaced air mass and, second, a passive movement rising on the thermal currents, being carried up and over and deposited in the foothills as the thermal air cooled and came back down as convections.

Later, daily checks consisting of body counts at five locations on the valley floor between the Semi Tropic area and the eastern foothills gave no indication of movement along the valley floor. Daily counts at five stations along the western foothills, however, showed a fairly good correlation with those made in the eastern foothills, giving some emphasis to a possible thermal convection mode of transportation.

Since it was desirable from the standpoint of the Kern Mosquito Abatement District to define the origin of these flights as quickly as possible, and strong circumstantial evidence pointed to the Semi Tropic area as the source, it was decided to attempt marking in this area in 1951, using radio-active phosphorus as a tagging agent. Counting at the previously established stations and general area inspections would be continued to establish the pattern more firmly.

Although the marking with radio-active phosphorus did extend our knowledge of the proven flight range of *Aedes nigromaculis* in California to 7½ miles, it was considered a failure for the purposes of this study. The prime factor was probably inability to mark sufficient numbers of mosquitoes. Other factors were the necessity of releasing from a single point when the source was over a wide area and the relatively short half-life of P^{32} which restricted marking to a fairly short period of time. Handling procedures require much special equipment and specially trained personnel. Tanks for holding larvae in P^{32} solution are stationary and release must be made from that point. The collection and transportation of larvae in hot weather may affect them adversely and limits the numbers of adults which may be released.

In the original consideration of marking media, dyes were discarded because of the time that would be involved in the development of techniques for marking and recovery; however, on second consideration, they seemed to avoid the basic faults of radio-active isotopes in regard to the specific problem at hand. Advantages that dyes seemed to offer were: non-hazardous dyes can be used freely throughout the source area wherever adult mosquitoes are available, and sprayed directly on the adult mosquitoes. Dyes can be applied on emerging swarms of mosquitoes whenever and wherever they are available, and handling presents no problem. By spraying dyes on adults the larval development is not affected in any way and almost limitless numbers of adults may be marked.

In preliminary field trials using fluorescene dye (navy sea marker) at 14 ounces in 2 gallons of water, emerging swarms of *Aedes* adults were sprayed with an 8002 Chicago Spraying Systems fan nozzle at the rate of approximately 4 gallons per acre. After 10 minutes, attacking adults were collected with a chloroform tube and returned to the laboratory, where they were immersed individually in 5 cc of water in a small test tube. Dye could be detected under a strong ultra-violet source in the rinse water from 70 percent of the mosquitoes so treated.

Further field trials with this material developed several problems, not the least of which was a natural fluorescence which leached out of the mosquitoes if they remained in the water for longer than a half hour or so. The color of this fluorescence under ultra-violet light was very similar to that of the fluorescene.

Other water soluble substances were tested and soluble Rhodamine "B" was finally selected for further trials. Although this material has a solubility of only slightly more than 0.25 percent in water, it was readily visible under ultra-violet light in dilutions as low as one part in 500 million.

Applications were made over emerging swarms in the field, using a 0.25 percent solution with Chicago Spraying Systems 8002 fan nozzle at 80 to 100 pounds pressure. Adults were collected from the body both before and one-half hour after the dye application for checking.

It was found that recovery of the dye by placing the mosquito on a sheet of white water color paper and placing a drop of absolute methyl alcohol on it was much more rapid and simpler than immersing mosquitoes in test tubes of water. The dye is transferred to the paper by the alcohol. The paper is then allowed to dry and is examined under an ultra-violet light. Using this method, 70 percent of the Rhodamine "B" sprayed mosquitoes were marked. No recoveries were made at any time from pre-application checks.

Due to the late beginning of the 1955 season, some of the planned developmental work was foregone. This included the use of stickers and spreaders, which might or might not have increased recoveries. Dye applications were made primarily with power sprayers.

A total of 25 dye applications were made over a period of 54 days. The applications were made on seven major *Aedes* sources lying roughly in a north-south line approximately 20 miles long, (see Fig. 1) and at right angles to the direction of the air mass movement suspected of initiating the flights.

Mosquitoes for dye recovery were collected in Wasco, Shafter and Wildwood, approximately six and eleven miles east and five miles south of the dye area, respectively, and in the foothill area of Bakersfield, approximately 28 miles east, southeast of the nearest dye location. Mosquitoes were collected primarily by body collections, 12 men spending from one-half to three hours each morning. *Aedes* taken in eight routinely operated light traps were also examined.

A total of 21,990 mosquitoes were collected in the recovery areas and tested for dye. By far the greatest numbers were taken from the Bakersfield area. Sixty marked specimens were recovered from the Bakersfield area on 24 different days and 6 different flight periods. Twelve recoveries were made from the Wasco area and two from the Wildwood area. The majority of the Bakersfield recoveries (34) were made on three occasions, when a major dye application was followed immediately by a heavy flight into the foothill area.

Since a mosquito abatement district is not a research agency, there is much of interest that was left undone. We did not demonstrate the complete extent of dispersion and might have delved further into the meteorological aspects of the problem. Neither do we feel that we know the full extent of the area of origin of the flights. We do feel that we have demonstrated a mass movement of *Aedes* mosquitoes over a distance of 20 to 30 miles, and by extension to known correlated limits, over a distance of at least 58 miles.