The initial effect of the spray on mosquitoes, mainly *Aedes* spp., was to reduce the landing rate by 86 per cent in dense forest and by 98 per cent in open forest. The long-term effect was to reduce the average landing rate from 9–10 to 2–3 per minute; four weeks after spraying the average landing rate in the sprayed area was 3.2 per minute as compared with 12 per minute in the unsprayed area. Average biting rates in the sprayed and unsprayed areas showed similar results.

The initial effect on black flies was to reduce their landing rate by approximately 70 per cent, although results were highly variable. The landing rate in the sprayed area was approximately 50 per cent of that in the surrounding unsprayed area for two weeks after spraying, 60 per cent after three weeks, and 80 per cent after four weeks.

Literature Cited

TWINN, C. R., A. W. A. BROWN, AND H. HURTIG. 1950. Area control of mosquitoes by aircraft in sub-arctic Canada. *Proc. 37th Annual Meeting New Jersey Mosq. Exterm. Assoc.*, pp. 113–140.

RESEARCH ON MOSQUITOES BY THE BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE DURING 1950

HARRY H. STAGE

Bureau of Entomology and Plant Quarantine, Agricultural Research Administration
U. S. Department of Agriculture

This is a brief summary of the research on mosquitoes carried on by the Bureau of Entomology and Plant Quarantine during 1950. The information has been made available to me by Alan Stone, taxonomist in the Washington, D. C., office; A. W. Lindquist, in charge of the Corvallis, Oregon, Laboratory; W. V. King, in charge of the Orlando, Florida, laboratory; and R. C. Roark, of the Beltsville, Maryland, Agricultural Research Center. The taxonomic investigations and those conducted at Corvallis and at the Beltsville Agricultural Research Center are financed by regular appropriations from Congress, whereas those at Orlando are financed by funds allotted by the Department of Defense.

TAXONOMY

Work on the taxonomy of mosquitoes consisted almost exclusively in assisting outside research workers with the loan of specimens, providing notes on types and other specimens in the United States National Museum, and giving aid to visiting workers. John Lane, from Brazil, spent nearly four months in Washington studying Neotropical mosquitoes. W. H. W. Komp and L. E. Rozeboom also spent some time in the Museum on various mosquito problems. Important loans were made to Walter J. LaCasse, P. F. Mattingly, R. M. Bohart, Robert Matheson, E. B. Thurman, R. F. Darsie, Jr., and W. B. Hull. The only important lot of mosquitoes sent in for determination was a fine collection of Iranian species from R. P. Dow. One paper, a description of the larva of *Culex foliaceus* Lane from the coast of Brazil, was published by Alan Stone.

INSECTICIDES

RESEARCH AT THE BELTSVILLE AGRICULTURAL RESEARCH CENTER

The recent development of allethrin—the so-called synthetic pyrethrum—by M. S. Schechter and F. B. La Forge is an

outstanding achievement. This material will undoubtedly serve as an excellent alternate for pyrethrum in controlling mosquitoes. As you know, the extract of pyrethrum flowers is an ingredient in liquefied-gas aerosols used for controlling mosquitoes indoors. This material produces a quick knock-down of flies and mosquitoes although higher concentrations of allethrin are required to give results comparable to pyrethrins.

Allethrin is a synthetic extract made wholly from materials produced in this country. It can be used in the same ways and formulations as pyrethrum extract is used. As a result of excellent cooperation and exchange of information between the Bureau's chemists, who developed a method of synthesis, and representatives of chemical industries, this material was made available in commercial quantities in a remarkably short time—about one year from the time of the first public announcement of the synthesis. Allethrin has been substituted for pyrethrum extract in aerosols now in use by the Armed forces.

BIOLOGY AND CONTROL

RESEARCH AT THE CORVALLIS, OREGON, LABORATORY

Use of Radioisotopes.—Tagging mosquitoes and other insects with radioactive phosphoric acid has proved useful in studies on the flight range of mosquitoes. Laboratory work has been conducted to determine the methods of getting the radioactive material into the insects, and the dosages necessary to produce enough radioactivity so that it can be detected with suitable instruments. As far as can be determined, mosquitoes carrying radioactivity of at least 5,000 counts per minute (cpm) are not injured and no shortening of life has been observed.

Adult *Aedes* mosquitoes showed measurable radioactivity when fourth-stage larvae were reared to adults in water containing approximately 0.0001 microcurie (μc) of radioactive phosphorus (P^{32}) per milliliter. A concentration of one-tenth this amount, or 0.00001 μc, gave significant readings in adults reared from second-stage larvae that had been exposed in the radioactive medium.

Detectable amounts of radioactivity were present in *Culiseta incidens* (Thom.) reared from eggs to adults at concentrations of 0.0001 μc or less of P^{32} per milliliter of water. This species was also used in a test which showed that the counts per minute in each insect decreased as the number of larvae per volume of treated water increased. When eggs of *C. incidens* were reared to adults in a pan containing soil, water, and enough P^{32} to give a concentration of 0.001 μc per milliliter of liquid, the counts per minute averaged 516 for the males and 957 for the females.

Synergists for Allethrin.—Approximately 150 compounds have been tested to determine whether they enhance the effectiveness of allethrin when used as a residual treatment against adults of *Aedes vexans* (Meig.) and *A. sticticus* (Meig.). Only 16 of the materials showed some promise as synergists, and none of these were especially outstanding.

Larvicides.—Laboratory testing of new materials for use as mosquito larvicides has been continued. Studies on the susceptibility of different instars of mosquito larvae to several insecticides showed that *Aedes dorsalis* (Meig.) required higher concentrations in all instars than did the *A. sticticus* and *A. vexans.*

Laboratory tests have been conducted with various emulsifiers and wetting agents to be used with oils as mosquito larvicides. At dosages of only 4 or 5 gallons per acre some of the combinations gave excellent results, especially on pupae.

Adulticides.—Limited daytime migrations of adult snow-water *Aedes,* as observed in the Cascade Mountains, have provided a vulnerable time when they may be controlled by aerial sprays. In the evening, however, between 8 and 9:30 p.m., their biting is severe and their flight habits so extensive that aerial applications over small areas are relatively ineffective. Residual treatments of DDT or lindane

applied to vegetation during the day, at the rate of 2 to 4 pounds of DDT or 3 pounds of lindane per acre, gave excellent protection to personnel within the local infested areas. However, no control was obtained during the evening. DDT mist sprays discharged upwind from a camp controlled mosquitoes during periods when they were not migrating but gave only fair protection during the evening migration period. Pyrethrum sprays gave good protection during the evening migration period, if the sprays were discharged frequently.

RESEARCH AT THE ORLANDO, FLORIDA, LABORATORY

Larvicides.—Field tests were conducted on small plots (mostly 1,000 square feet in size) to compare the effectiveness of DDT, dieldrin, lindane, toxaphene, chlordane, and parathion as oil solutions and as emulsions against larvae of anopheline mosquitoes (chiefly *Anopheles crucians* Wied.).

The materials were applied under favorable weather conditions with a specially constructed flit-gun sprayer at a uniform rate of 10.4 cc. per 1,000 sq. ft, and different dosages were obtained by varying the concentration of the material in the sprays. The dosages used in these tests ranged from 0.00035 to 0.025 with emulsions and from 0.0015 to 0.05 with oil solutions.

Dieldrin was the most effective of all the compounds tested. DDT and parathion were only slightly less effective than dieldrin, and both were considerably better than lindane, chlordane, or toxaphene. Four of the compounds were tested both as emulsions and as oil solutions, and all were more effective in the emulsion form. The difference was more marked with DDT than with the other three. Atomized fuel oil alone showed considerable toxicity to anopheline larvae but was highly erratic in different check plots.

Field tests were also conducted on small plots to compare the effectiveness of DDT, benzene hexachloride (40 per cent gamma isomer), dieldrin, and toxaphene against the larvae of salt-marsh mosquitoes (*Aedes taeniorhynchus* (Wied.) and *A. sollicitans* (Walk.)) in the Cocoa Beach area, where DDT has been used extensively for several years, and in the Titusville Beach and Salt Lake areas, which have been treated only occasionally. The insecticides were applied at dosages ranging from 0.003 to 0.2 pound per acre with a hand-pressure sprayer equipped with a fine nozzle. Solutions were applied at the rate of 4 gallons per acre, and the concentration of insecticide was varied to give the desired dosages.

Dieldrin was slightly more effective than benzene hexachloride and toxaphene, and all three were considerably more effective than DDT.

Dieldrin showed about the same degree of toxicity to the two species in the test areas, whereas DDT appeared distinctly less toxic to *A. sollicitans* than to *A. taeniorhynchus*. Both DDT and benzene hexachloride were less effective against *A. taeniorhynchus* larvae in the heavily treated area (Cocoa) than in the occasionally treated area (Titusville), whereas with toxaphene the reverse was true.

Tests with Aerial Sprays.—Aerial larvicide tests were conducted on 40-acre plots with oil solutions of DDT, lindane, dieldrin, aldrin, toxaphene, and heptachlor, and with emulsions of lindane and heptachlor. The tests were run in areas that had been treated either intensively or only occasionally with DDT. Sprays were applied at the rate of 4 quarts per acre with a PT-17 airplane equipped with underwing spray booms.

In the occasionally treated areas, applications of 0.1 pound per acre of lindane, dieldrin, and heptachlor gave nearly perfect control of mixed populations of *A. taeniorhynchus* and *A. sollicitans*. Heptachlor and lindane at 0.05 pound per acre, and toxaphene at 0.2 pound per acre, gave close to 90 per cent control. Lindane emulsion at 0.025 pound per acre gave similar results, but oil solutions at this dosage were less effective. Aldrin at 0.1 pound per acre showed only 69 per cent control.

In two tests in the intensively treated areas, aldrin at 0.2 pound per acre was ineffective against *A. sollicitans*, and DDT at 0.4 pound per acre gave only 77 per cent control of a mixed population of *A. sollicitans* and *A. taeniorhynchus*. The fact that both materials at lower doses gave much better results in the occasionally treated areas indicated that the larvae in the intensively treated areas were much more resistant to these chemicals.

Preflood Treatments for Control of Salt-Marsh Mosquito Larvae.—Observations were made throughout the season on 11 salt-marsh plots to which mosquito larvicides had been applied as preflood or prehatching treatments in April and early May. The plots were each 2 acres in size, and the materials included in the tests were DDT, toxaphene, and dieldrin applied as wettable-powder dusts. Eight of the plots were located in the Cocoa Beach area, which had been intensively treated with DDT for several years and where the mosquito population has shown increased resistance to DDT. The other three plots were in the Titusville Beach area, which had been treated only occasionally. One or two untreated check plots were left with each group of test plots.

Preflood treatments of 0.5 and 1 pound per acre of dieldrin and toxaphene gave very good reductions of larval breeding through two to four floodings in the intensively treated area of Cocoa Beach, and were even more effective in the occasionally treated area of Titusville Beach.

DDT at 1 and 3 pounds per acre showed fair to moderate reductions through two to four floodings in the Cocoa Beach area, but was less effective than a 2-pound treatment in the Titusville area.

Resistance of Salt-Marsh Larvae to Different Insecticides.—Twenty-seven lots of salt-marsh mosquito larvae were tested in the laboratory for susceptibility to DDT, lindane, and toxaphene. Four of the lots were from an area that had been intensively treated with DDT in recent years and where the larvae showed considerable resistance to DDT in 1949; 23 lots were from occasionally treated areas. Three of the four lots from the intensively treated area showed a high degree of resistance to DDT, and one of the three also showed marked resistance to lindane. Three of the lots were slightly less susceptible to toxaphene than larvae from the occasionally treated areas, and the other was about equally susceptible.

Larvae from several occasionally treated areas showed equal susceptibility to DDT, lindane, and toxaphene, except for one lot of *Aedes sollicitans* which required relatively high concentrations of all the larvicides. A second lot of this species collected on the same marsh at the same time was more susceptible than most of the *A. taeniorhynchus* larvae, which predominated in most of the tests.

Dieldrin was the most effective material against larvae from intensively treated areas, and was more effective against larvae from occasionally treated areas than lindane or toxaphene. All three of these materials were somewhat better than DDT.

Adulticides.—Aerial spray tests with different insecticides against salt-marsh mosquito adults were conducted in the Cocoa Beach area, which had been intensively treated with DDT from 1945 to 1949 and with benzene hexachloride in 1950, and the Haulover Canal and Titusville Beach areas which have been treated occasionally with DDT. Treatments were made with a PT-17 plane, at the rate of 4 quarts per acre, at a swath interval of 100 feet. The concentration of the insecticides was varied to give different dosages. Most of the plots were 40 acres in size and so arranged that a number of tests could be run in a large area where conditions were similar.

Lindane and technical benzene hexachloride (40 per cent gamma isomer) as oil solutions gave excellent control of both species of salt-marsh mosquitoes at dosages of 0.1 and 0.05 pound of gamma isomer per acre in each of three different locations, and were more effective than lindane emulsion at a dosage of 0.05 pound. Lindane was also tested at 0.025 pound per acre, both as a solution and as an emulsion, but

did not give satisfactory control at this dosage.

Dieldrin at 0.1 and 0.15 pound per acre gave good to excellent reductions of both species of salt-marsh mosquitoes in intensively and occasionally treated areas, and gave good control at 0.05 pound per acre in the latter type of area but not in the former. Heptachlor showed almost perfect control at 0.05 and 0.1 pound per acre and appeared of considerable promise as a possible substitute for DDT for the control of salt-marsh species.

Tests Against Alaskan Aedes.—Three DDT formulations used in Alaska in 1949 were re-tested on large plots in 1950. These formulations included an airplane spray solution containing 20 per cent of DDT, 20 per cent of fuel oil, and 60 per cent of Paccosol; a 20 per cent DDT spray with 1 per cent of Triton B-1956 added; and an emulsifiable concentrate containing 20 per cent of DDT, 10 per cent of Triton X-100, and 70 per cent of Velsicol AR-50-G. The sprays were applied with a C-47 plane at rates of 25, 75, and 123 ml. per acre, or 0.1, 0.03, and 0.05 pound of DDT per acre.

All the formulations were highly effective at dosages of 0.03 and 0.05 pound of DDT per acre, larval reductions ranging from 92 per cent to 98 per cent. At a dosage of 0.01 pound, neither the 20 per cent spray with 1 per cent of a wetting agent nor the emulsifiable concentrate were very effective, but the latter gave slightly higher kills. The results of these tests did not permit a conclusion as to the most effective of the three formulations, but suggest that future evaluations should be made on the basis of somewhat lower dosages than were used in 1950.

Observations in large areas treated for mosquito control in 1948 and 1949 with accumulative totals of 0.3 and 0.7 pound of DDT per acre showed 99 per cent less larvae in 1950 than in adjacent untreated marshes. On the basis of pretreatment counts, the plot treated with 0.3 pound of DDT per acre in 1949 showed a larval reduction of 95 per cent in 1950. Similarly, the plot treated with 0.3 pound in 1948 showed a reduction of 86 per cent in 1949, and after additional treatment of 0.4 pound per acre in 1949 showed a further reduction in 1950 of 89 per cent, or 98.5 per cent of the original population in 1948.

DDT at 0.2 pound per acre was ineffective in the intensively treated area and gave only fair control in the other areas, but at 0.4 and 0.5 pound per acre gave satisfactory results even against the DDT-resistant adults in intensively treated areas. Toxaphene at 0.2 pound per acre was fairly effective in previously untreated areas but was not tested elsewhere. Aldrin at 0.1 pound per acre was ineffective.

Tests of Ground Fog Machines Against Alaskan Aedes *Adults.*—Extensive tests were conducted in Alaska in 1950 to determine the effectiveness and practicability of ground fog machines for the control of adult mosquitoes. In roadside tests, applications of 3.6 to 10 gallons of 10 per cent or 20 per cent DDT-oil solution per front mile (3 to 17 pounds of DDT) with a Tifa, Dyna-Fog and jeep-exhaust generators caused 81 per cent to 100 per cent reductions in adult biting rates within 2 to 4 hours after treatment. After 12 hours reductions were poor. Almost all the plots had sufficient adult populations within 24 to 60 hours to justify re-treatment, regardless of the amount of DDT applied. Repeated treatments of the same area apparently did not produce an effective residue, although a total of 0.5 to 0.8 pound of DDT per acre (based on a 120-yard swath) was applied in certain plots over a 2-week period.

Observations and counts indicated that with winds of 1 to 4 mph. the effective penetration of the DDT fogs was limited to about 600 feet, and was somewhat greater for the first 360 feet than the next 240 feet. Little or no reduction was obtained with winds greater than 4 mph. or during daylight hours. The optimum conditions for fog applications appeared to be between 9 p.m. and 2 a.m., when inver-

sion was favorable and winds were less than 4 mph.

Practical tests on the Big Delta Army Base indicated that considerable immediate relief from mosquitoes could be obtained with the Tifa and Dyna-Fog machines but even when adult mosquito populations were relatively low, as they were in 1950, treatments were needed almost daily to keep populations at a sub-annoyance level.

THE USE OF INSECTICIDES FOR MOSQUITO CONTROL IN CALIFORNIA

A. F. GEIB

Manager, Kern Mosquito Abatement District
Bakersfield, California

Mosquito control in California now encompasses over 20,000 square miles, with Districts located throughout the length and breadth of the State. All control programs are primarily larviciding operations augmented by adulticiding through aerosol and spray applications. The Districts may be divided into those primarily concerned with salt marsh and coastal problems and those concerned with problems arising from an irrigation type agricultural economy. But this in no way seems to reflect the great diversity of breeding problems to which larvicidal applications must be adapted. These range from brackish and highly saline salt marsh along the coastal bays to clear river run-off in the interior, and from constantly flooded rice paddies in the Sacramento Valley to pasture, alfalfa and cotton lands, requiring repeated flooding and drying in the San Joaquin Valley. There are also the myriads of artificial containers collecting water from lawn sprinkling, etc. in the urban areas.

Aedes mosquitoes breeding in intermittent waters are a problem both in the salt marshes of the coastal areas and in the irrigated agricultural valleys. *Culex* mosquitoes are a problem throughout the state in any permanent or semipermanent waters. The *Anopheles* are a problem primarily in the north San Joaquin and Sacramento Valleys, breeding in extensive rice paddies and in the ditches carrying the water to and from these fields.

Before World War II diesel oil was the primary material used for a larvicidal spray. Some pyrethrum in various formulations was used for adulticiding when necessary.

When DDT became available in the spring of 1946 the mosquito control picture in California entered a period of rapid change. Economy of use made mosquito control possible in areas of low assessed value. Low phytotoxicity made it possible to spray among crops without danger of injury and the fact that emulsible concentrates easily mixed with any available water could be carried and applied at low gallonage per acre made it possible for highly mobile equipment to be developed which could operate, independent of any set supply source, for a full day's work, resulting in a considerable saving of labor time.

The first DDT used in any quantity in California was a 25 per cent emulsible concentrate purchased from War Surplus stock. This material formed an excellent, highly stable emulsion which proved to be very satisfactory for use as a larvicide both by ground and aircraft spray application. Wettable and dry base dusts and oil solutions were also tried by plane and ground application. Of these materials DDT emulsible concentrate was judged, from the viewpoint of effectiveness, economy and ease of handling, to be the best all around material for use in ground spray applications. For aerial spray work emulsions seem to be more satisfactory in some areas and oil solutions in others.

When supplies of this War Surplus