the insecticides, when treatments have been discontinued and residues on walls and in the soil disappear, then the chlorinated hydrocarbons will again become useful as chemicals to reduce fly populations.

4. Still greater emphasis should be placed on sanitation. Insecticides should be used only to augment the fly control obtained by strict sanitation. There is no substitute for sanitation.

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For further reading on resistant flies, Mr. Bruce suggests his articles, Latest Report on Fly Control, *Pests, volume 17, number 6, pages 7, 28 (1949), and* House Fly Tolerance for Insecticides, *with G. C. Decker, Soap and Sanitary Chemicals, volume 26, number 3, pages 122–125, 145–147 (1950), and articles by—*

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Mosquitoes and DDT

W. V. King

Increased resistance to DDT has been recorded for several species of mosquitoes in widely separated parts of the world. Included are the house mosquitoes, *Culex pipiens* in Italy and *C. quinquefasciatus* in India; two salt-marsh species, *Aedes taeniorhynchus* and *A. sollicitans,* in Florida; and two floodwater species, *Aedes nigromaculis* and *A. dorsalis,* as well as *Culex tarsalis* in California. An encouraging fact is that two species of *Anopheles* failed to show increased resistance in areas where they had been exposed for several years to DDT residual treatment in buildings.

E. Mosna was apparently the first to report increased resistance in a species of mosquito, *Culex pipiens autogenicus* (*molestus*) from the Pontine marshes in Italy. He found many live specimens of the species in bedrooms of houses in May 1947, where for the second year 5 percent DDT in kerosene had been applied as a residue for the control of *Anopheles.* Specimens he collected from the interiors were exposed to the treated walls and were alive after 48 to 72 hours, but specimens from a laboratory strain died within 3 to 5 hours. He thought it possible that two races of this variety of mosquito might exist, distinguished basically by the different grade of resistance to DDT. Laboratory tests with the eighth generation reared from resistant material showed that the resistance was transmitted through eight generations without marked diminution. From preliminary laboratory and field tests with chlordane and benzene hexachloride, Mosna learned that the insecticides had residual action lasting more than 4 months and were there-

fore suited to practical control of *Culex* that are resistant to DDT.

In India, from experiments conducted for 10 months, J. F. Newman and others learned that successive generations of the southern house mosquito exposed in the laboratory to DDT residues showed a marked increase in resistance to DDT. A 20-minute exposure caused 100 percent mortality of females originally, but no mortality resulted from 30-minute exposures a few months later. A similar resistance to benzene hexachloride also was shown.

The failure of DDT sprays to give satisfactory control of the common salt-marsh mosquito and another salt-marsh species, *Aedes taeniorhynchus,* in Broward County in Florida, was first noticed in 1947 in Hollywood, where much DDT had been applied in previous years to control heavy infestations.

The failure was observed again in 1948 and 1949, when similar difficulty was experienced in Brevard County near Cocoa Beach and the Banana River Airbase, where an extensive salt marsh had been treated repeatedly with DDT sprays the previous 4 years. In June 1949 the results of aerial spraying operations in the area were checked by members of the Orlando laboratory of the Bureau of Entomology and Plant Quarantine. It became evident that satisfactory reduction of adults of the two salt-marsh species *A. taeniorhynchus* and *A. sollicitans* was not obtained with the standard dosage of 0.2 pound of DDT per acre. Even twice that dosage failed to give as good control as had been obtained with the standard dosage. This indication of increased resistance was confirmed by laboratory tests in which larvae and reared adults of *A. taeniorhynchus* and *A. sollicitans* were compared for susceptibility to DDT with similar specimen material of *A. taeniorhynchus* from other areas in the same county that were not known to have received DDT applications previously or only an occasional treatment for adult control. *A. sollicitans* were not present in the untreated areas at the time the collections were made for the tests.

The evidence from the laboratory tests demonstrated the increased tolerance of the specimens from the treated areas. In the larvicide tests, the mortality of fourth-stage larvae averaged about 16 percent, compared with an average of nearly 90 percent for the control larvae. Similarly, in space-spray tests with 1 percent DDT solutions against reared females, the comparable figures were 18 percent and 83 percent. The results indicated a fourfold increase in tolerance or more. Larvae of *Aedes taeniorhynchus* collected in 1949 from a treated area in Sarasota County on the Gulf Coast also showed increased resistance.

In tests on mosquito specimens from Brevard County, chlordane and benzene hexachloride, both technical and refined (lindane), produced about the same mortalities of larvae and adults from the treated areas as from untreated areas at similar dosages. That was true also of parathion in larvicide tests. Parathion was not included against the adults. TDE, like DDT, was much less toxic to the specimens from the treated area. Toxaphene was somewhat less toxic. Lindane was by far the most toxic compound to adults, and parathion to the larvae from all areas.

Aerial spray tests with several insecticides were also carried out against the DDT-resistant mosquitoes. Lindane, the most effective of the insecticides tested, gave good control of adults at dosages of 0.05 and 0.1 pound per acre. Technical benzene hexachloride (12 percent gamma) at 0.2 and 0.4 pound and dieldrin and parathion at 0.05 and 0.1 pound gave results nearly equal to lindane. Chlordane and DDT at 0.2 and 0.3 pound per acre and toxaphene at 0.2 pound were not highly effective in most tests.

Larvicidal tests on small plots were conducted with several insecticides applied as emulsions. In the Cocoa Beach area DDT was much less effective than in untreated areas, but the

other materials—dieldrin, parathion, lindane, technical benzene hexachloride, and toxaphene—all gave good and approximately similar results in both the treated and untreated marshes. Dieldrin and parathion were the most effective at dosages of 0.025 and 0.05 pound per acre, closely followed by lindane and toxaphene.

Indications of increased resistance to the effects of DDT in larvae of *Aedes nigromaculis* and *A. dorsalis* in Kern County, Calif., were noticed in the fall of 1947 and early in 1948 on a large ranch that had been regularly treated by truck and plane and had also been used for experiments on the applications of DDT emulsion siphoned into the irrigation water. The dosage was increased from 0.15 to 0.25 parts per million with continued failure. Later a part of the fields was treated with DDT by plane at the rate of 0.4 pound per acre and part with toxaphene at 0.3 pound. The toxaphene killed all stages of larvae, but the DDT failed to kill even the first stages. Complaints that DDT was not giving good control of the larvae of *Culex tarsalis* were also received in the district at about the same time.

R. M. Bohart and W. D. Murray reported that unsatisfactory results in the control of *Aedes nigromaculis* was experienced in Tulare and Merced Counties in 1949. To confirm the field observations, laboratory tests were made with larvae of the species collected in three pastures, which had previously received repeated DDT larvicide applications, in the mosquito-abatement district in Tulare County. They compared the larvae with larvae from three pastures in Kings County not known to have been previously treated with DDT. Based on the dosages required to cause 50 percent mortality, the average for the larvae from Tulare County was more than 10 times that for the control larvae. The least resistant of the larval lots from the treated fields required about three times as much DDT as the most resistant lot from the control area. In comparative tests between DDT and toxaphene, the latter was considerably the more toxic to the DDT-resistant larvae but less toxic to the control lots.

DDT residues applied to walls of living quarters and other buildings have been widely used in different countries to control carriers of malaria. Tests to determine whether an increase in tolerance had occurred were carried out in two areas where this method of control had been in operation for several years. The results were negative.

In the Mexican village of Temixco, DDT sprays were applied to the interior wall surfaces of all houses and other buildings once in early spring each year from 1945 to 1948. The sprays reduced markedly the numbers of *Anopheles pseudopunctipennis* in the village and in the surrounding rice fields. Laboratory tests were run in 1948 under the direction of J. B. Gahan and Wilbur G. Downs to determine the relative susceptibility of adults that had been collected in the village and the untreated village of San Jose, about 10 miles away. In June and July 96 tests were conducted with about 2,000 adult mosquitoes from each village. The insects were reared from gravid females collected in the two places and were tested by exposure to cloth panels impregnated with DDT. The average mortality was somewhat higher for the mosquitoes from the treated village than it was for those from the untreated village (56 percent versus 43 percent for the two sexes combined). The finding seemed to demonstrate that no loss of susceptibility had occurred.

G. F. Ludvik and others reported in 1950 on the first year of a study of DDT resistance in *Anopheles quadrimaculatus* in the Tennessee River Valley after 5 years of routine treatment, in which were used DDT residues against larvae and adults. They subjected specimen material to a variety of tests in comparison with similar material from untreated areas. The comparisons consisted of laboratory larvicidal tests in suspensions of

DDT, exposures of larvae in pans to aerial DDT sprays, exposures of adults to DDT-treated panels, and release of adults in residue-treated rooms. The mosquitoes from treated areas showed slightly greater tolerance to DDT in some of the tests, but the workers concluded from their preliminary studies that they had not developed an outstanding resistance.

R. W. Fay and others have reported the results of preliminary experiments to determine the possible development of a resistant strain of *Anopheles quadrimaculatus*. Adults of an insectary-reared colony of the species were exposed for four successive generations to DDT-treated panels for enough time to give mortalities of about 66 percent. Eggs from the surviving females then were obtained for rearing. In tests of susceptibility to DDT of the exposed strains, the mean mortality showed a slight but statistically significant drop in the first generation. No change occurred during the next three generations but was followed by an increase to the original level in the first generation after discontinuance of exposure to DDT. In tests against other insecticides, a similar loss of susceptibility was shown to methoxychlor but not to chlordane, benzene hexachloride, aldrin, or TDE (DDD). Because the pattern of increase and decrease in resistance was basically different in these tests from that reported for house flies (in which the changes in each direction were much more gradual) further confirmation of these results seems necessary before conclusions can be drawn.

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Dr. King cites the following articles for some of the information in his article and suggests them for further reading:

J. H. Bertholf: DDT Resistant Mosquitoes in Broward County, Fla., *Florida Anti-Mosquito Association Proceedings, pages 80–83. 1950.*

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