DDT Resistance in A. Quadrimaculatus

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RESISTANCE to dieldrin in *Anopheles quadrimaculatus* Say has been demonstrated in Mississippi (*1*). Although this species showed a lowered susceptibility to BHC and chlordane, it was susceptible to DDT. Kruse and associates (*2*) reported possible DDT resistance in *A. quadrimaculatus* in the lakes of the Tennessee Valley Authority area, but subsequent studies (*3*) indicated this presumed resistance was due to other causes. Hawkins and associates (*4*) stated that DDT was still the insecticide of choice in the area, after 13 years of larvicidal applications. This paper describes the detection of a DDT-resistant population of *A. quadrimaculatus* which was recovered from a tributary of the Clark Hill Reservoir, Ga.

Clark Hill Reservoir is a multipurpose impoundment built and operated by the Corps of Engineers, U.S. Army, on the Savannah River approximately 22 miles north of Augusta, Ga. At maximum power (pool elevation 330 feet above mean sea level) it covers 70,000 acres with a shoreline of 1,060 miles. Impoundment began in 1951 and full pool was reached in May 1953. Average seasonal operating levels cover a range of about 12 feet.

Operational Procedures

Following general recommendations of the Public Health Service regarding construction and project operation for mosquito control, the Corps of Engineers conducted pre- and post-impoundment anopheline density counts in conjunction with shoreline maintenance and a larviciding program. Beginning in 1952, larvicide treatments were made by contract aircraft, at a rate of 0.08 to 0.20 pound of DDT per acre, to selected areas where weekly adult counts were high. The average number of *A. quadrimaculatus* per station inspection on the entire reservoir and the pounds of DDT applied during the period 1952 through 1959 are given in table 1. Extreme drought in 1954 and 1955 caused a total drawdown of 33.5 feet and failure to fill by about 10.5 feet in 1955, materially reducing the *A. quadrimaculatus* breeding potential during those years. The highest annual average of *A. quadrimaculatus* per station inspection for a single station has occurred each year since 1953 at a stable, station 41–A, adjacent to the Fishing Creek arm of the reservoir in Georgia. Table 2 gives the annual averages of *A. quadrimaculatus* per inspection for this station and the number of DDT treatments in that area per year.

In 1959, late filling of the reservoir (June 5 instead of May 1) and two floods, which caused rising pool elevations in July and September, resulted in high counts of *A. quadrimaculatus*

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in many parts of the reservoir. Despite regular applications of DDT larvicide, the weekly adult *A. quadrimaculatus* count at station 41–A was more than 300 specimens for 9 consecutive weeks beginning June 30. During the season the area was larvicided 18 times at approximately weekly intervals from May 7 to September 18.

In late July 1959, samples of DDT larvicides and solvents were submitted to the Technical Development Laboratories, Technology Branch, Communicable Disease Center, for testing their larvicidal action. These tests showed that the insecticide formulations as used in the control operations were fully effective against susceptible *A. quadrimaculatus* larvae. As a result, suspicion arose that the Clark Hill *A. quadrimaculatus* might be resistant to DDT, and several hundred live adults were brought to the Technical Development Laboratories for testing.

Table 1. Average number A. quadrimaculatus per station and pounds of DDT applied yearly, 1952 through 1959, Clark Hill Reservoir, Ga.

Year	Average number *A. quadrimaculatus* per station	Pounds of DDT applied
1952	12. 31	8, 346
1953	4. 43	5, 698
1954	. 85	4, 276
1955	1. 58	4, 941
1956	3. 34	7, 635
1957	3. 96	9, 621
1958	2. 46	10, 605
1959	15. 85	10, 788

Table 2. Average annual A. quadrimaculatus count, station 41–A, 1952 through 1959

Year	Average number *A. quadrimaculatus* per inspection	Number of DDT treatments
1952	3. 93	8
1953	24. 40	16
1954	5. 73	13
1955	13. 73	16
1956	30. 52	17
1957	29. 50	17
1958	40. 28	22
1959	[1] 200. 00	18

[1] Exact average not determined. Nine inspections were reported as over 300.

Table 3. Comparative susceptibility of third instar larvae of Clark Hill Reservoir and Savannah laboratory strains of A. quadrimaculatus to DDT-ethanol and dieldrin-ethanol solutions

Concentration (ppm)	Percent mortality after 24-hour exposure			
	DDT		Dieldrin	
	Clark Hill [1]	Savannah [2]	Clark Hill	Savannah
0.004	2	36	19	100
0.02	8	100	29	100
0.1	2	100	38	100
0.5	16	100	86	100
2.5	49	100	100	100
Check	16	4	16	4

[1] Mortalities adjusted according to Abbott's formula.
[2] Nonresistant laboratory strain.

Resistance Tests

The initial tests were run with larvae and adults obtained from eggs laid by field-collected specimens. The data obtained on third instar larvae, compared with results on larvae of the nonresistant Savannah laboratory strain, are given in table 3.

The number of available adults of the Clark Hill strain limited adult tests to the highest concentration of DDT- or dieldrin-Risella oil papers. One-hour exposures to 4 percent DDT-Risella oil paper and to 1.6 percent dieldrin-Risella oil paper gave only 4 and 38 percent kills, respectively. Adult mortalities for the Savannah laboratory strain at those dosages were 100 and 97 percent, respectively.

On September 21 and 22, adult specimens of *A. quadrimaculatus* were collected and tested in the field. Tests on September 21 at 1- and 2-hour exposures to papers impregnated with 1, 2, and 4 percent DDT in Risella oil indicated maximum mortalities of 34 percent, but the check mortality was unusually high (22 percent). On September 22, further tests showed that the maximum DDT concentration gave

Table 4. Percent mortality of field-collected female A. quadrimaculatus exposed to DDT-Risella oil papers for 2 or 4 hours

Percent DDT	Exposure period (hours)	Number specimens	Percent mortality 24 hours after exposure
1	2	27	4
2	2	24	0
4	2	23	17
1	4	25	4
2	4	26	23
4	4	130	18
Check	4	24	4

only minimum mortality of the strain even with a 4-hour exposure period (table 4).

Additional tests with these field-collected specimens and with the Savannah laboratory strain were made at Savannah on September 24 with DDT- and dieldrin-treated papers. The data are given in tables 5 and 6.

To check the possible effect of season on the susceptibility level of field specimens, *A. quadrimaculatus* females were collected in the vicinity of Savannah, Ga., and exposed for 1 hour to 4 percent DDT-Risella oil-treated papers. The 50 specimens so tested gave a mortality of 96 percent, which is the normal response of a DDT-susceptible strain.

Discussion

The preceding data establish that *A. quadrimaculatus* from the Clark Hill Reservoir area are resistant to DDT, both as larvae and adults. The lack of susceptibility data prior to insecticidal treatments does not permit the conclusion that the resistance was developed by the species through selection. However, the history of insecticidal treatment and the rising *A. quadrimaculatus* densities strongly suggest that this is the case.

This occurrence of DDT resistance in a field population of *A. quadrimaculatus* is of considerable significance in view of the fact that intensive efforts by workers of the Tennessee Valley Authority (*4*) and at the Technical Development Laboratories (*5*) to produce DDT-resistant strains by laboratory selection of adults or larvae, or both, have been unsuccessful. The presence of DDT-resistant *A. quadrimaculatus* in the Clark Hill Reservoir area and the continued absence of DDT-resistant populations in other impoundments (for example, TVA) again emphasize the fact that the same species occurring in various localities may show distinct differences in its response to an insecticide. These differences could be inherent in the genetic makeup of the species or they could arise from variations in the environment.

From the data on dieldrin in tables 3 and 6, it is apparent that the species also is resistant to dieldrin, but the level is below that shown for DDT. The data on adults (table 6) show a definite plateau response to an increase in the concentration of dieldrin; a specific character-

Table 5. Comparative susceptibility of Clark Hill Reservoir and Savannah laboratory strains of adult A. quadrimaculatus exposed to DDT-Risella oil-treated papers for 1 hour

Percent DDT	Mortality at 24 hours			
	Clark Hill		Savannah	
	Number specimens	Percent	Number specimens	Percent
1	82	0	81	23
2	84	1	79	89
4	82	0	80	100
Check	20	5	20	0

Table 6. Comparative susceptibility of Clark Hill Reservoir and Savannah laboratory strains of adult A. quadrimaculatus exposed to dieldrin-Risella oil-treated papers for 1 hour

Percent dieldrin	Mortality at 24 hours			
	Clark Hill		Savannah	
	Number specimens	Percent	Number specimens	Percent
0.4	74	28	81	35
0.8	81	31	80	96
1.6	80	36	80	100
Check	20	0	19	0

istic of resistance in field populations of mosquitoes. This resistance to dieldrin was somewhat unexpected since this insecticide has not been employed for mosquito control in the reservoir and its agricultural use in the general area is limited.

Summary

Tests with field-collected adults and with larvae obtained from eggs of field-collected adults established that *Anopheles quadrimaculatus* from the Clark Hill Reservoir, located near Augusta, Ga., are highly resistant to DDT. DDT has been used routinely on certain areas of the reservoir since 1952.

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(*4*) Hawkins, W. B., Moore, J. B., and Smith, G. E.: Tests on the resistance of *Anopheles* larvae in the region of the Tennessee Valley Authority. Indian J. Malariol. 12: 317–322, December 1958.

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Radiological Health Training

The Division of Radiological Health reports that presentation of short-term technical courses, part of the training program of the Robert A. Taft Sanitary Engineering Center in Cincinnati, is nearing completion of its most successful year. Over 500 professional personnel from Federal agencies, State and local health departments, colleges and universities, and industry attended the 19 sessions of 12 different courses conducted during fiscal year 1960. Added to these were 47 trainees from 11 foreign countries, plus 300 personnel of the division attending special field presentations. This represented more than double the enrollment of the previous year.

The program for fiscal year 1961 is again being expanded. This is reflected in an increase both in the number and frequency with which courses will be presented. New programs include a 1-week field presentation for scientists and engineers on "Environmental Radiation Surveillance"; a special 1-week course on "Radiological Health for Nurses," the first such program in this important area of public health; and a 2-week course, entitled, "Orientation in Radiological Health," specifically directed toward health educators and public information personnel.

In addition, sessions of the course on "Basic Radiological Health" are scheduled for presentation at the Southeastern Radiological Health Facility in Montgomery, Ala., and the Southwestern Radiological Health Facility in Las Vegas, Nev., recently dedicated by the Surgeon General. Sessions of the courses on "Radiological Health for X-ray Technicians" and "X-ray Protection" are scheduled for presentation at another new laboratory being developed by the Division of Radiological Health in Rockville, Md.

During the period July 1, 1960–July 1, 1961, requests for further information or reservations in these courses should be directed to the Chief, Training Program, Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio.