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# PAST ACHIEVEMENTS, CURRENT ACTIVITIES AND CONTRIBUTIONS, AND A VIEW TO THE FUTURE ON RESEARCH ON AND CONTROL OF MOSQUITOES BY THE U. S. PUBLIC HEALTH SERVICE

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The history of the Public Health Service during the past 164 years is closely linked with research on and control of mosquitoes and mosquito-borne diseases (1)*. The ravages of a mosquito-borne disease, yellow fever, were an important factor in the establishment of the Service in 1798 to provide for the relief of sick and disabled seamen, and in the subsequent broadening of its functions as a quarantine agency and the federal agency responsible for the public health.

During the first century of its existence, the Service instituted and directed quarantine activities to prevent the introduction of yellow fever and other diseases into the United States and the spread of epidemics within the country. For many years, beginning about 1880, Congress appropriated annually to the Service a continuing "epidemic fund" to provide the means of coping with outbreaks of yellow fever and other epidemics. From 1872 to 1905, the Service assisted States in, or wholly controlled the work of, suppressing yellow fever epidemics in the U. S. In 1898, Dr. Henry R. Carter demonstrated epidemiologically the extrinsic incubation of yellow fever—the time required to develop the disease in some outside host. This was of material assistance to Dr. Walter Reed and his U. S. Army associates in their later demonstration that yellow fever was transmitted by *Aedes aegypti*. During the last epidemic of yellow fever in the U. S. in New Orleans, La. in 1905, the Service demonstrated the effectiveness of controlling mosquitoes through screening, fumigation, oiling and salting, together with the isolation of the sick, as a means of controlling yellow fever epidemics.

*The otherwise unreferenced material in this paper relating to the history and accomplishments of the Public Health Service prior to about the last decade was taken from this excellent history of the Service.

During the two World Wars the Service carried on *Aedes aegypti* control programs around military camps. In 1937 control of *A. aegypti* around international airports and the disinsection of international aircraft were initiated and have been continued to the present. These operational activities were accompanied by a continuous program of research to develop new and improved methods of controlling *A. aegypti* and for the improvement and mass production of yellow fever vaccines. After May 1942, the Service produced and furnished to the U. S. Armed Forces all the yellow fever vaccine used in World War II.

Malaria investigations were begun by the Service in 1912. Field demonstrations carried out under the direction of Service personnel in North Carolina in 1913 and Mississippi in 1914 were the first demonstrations of malaria reduction in the U. S. by anti-mosquito methods.

During the next quarter of a century the Service carried on extensive programs of research on malaria and its control, and of assistance to States in malaria control demonstrations and operations. Some of the more important contributions of this earlier research by the Service on malaria control methods include the use of *Gambusia* minnows as a biological control agent, paris green as an anopheline larvicide, the screening of houses as a valuable protective measure, and the use of durable ditch lining in drainage systems.

During the relief programs of the 1930s, significant progress was made in malaria control by CWA, ERA and WPA programs under Service guidance. More than 30,000 miles of ditches were constructed and approximately 625,000 watered areas were drained.

During both World Wars I and II the Service was responsible for malaria control around military camps and industrial centers. The present Communicable Disease Center was a direct outgrowth of the World War II Malaria Control in War Areas program. In 1947, in cooperation with the affected States, CDC initiated the DDT house-spraying program to eradicate malaria from the United States. This was accomplished, for all practical purposes, by 1952 (2).

As in the case of its yellow fever work, the Service's operational activities against malaria were accompanied by a continuous program of research on all aspects of malaria—the parasite, the vector, and the control of both by various methods. This research is still in progress today.

The Service also has contributed significantly to the elucidation of the ecology of the arthropod-borne encephalitides in the U. S. and to the development of methods for controlling the mosquito vectors of these diseases.

In addition to its achivements with respect to the control of mosquito vectors of disease, the Service has contributed appreciably to a knowledge of the bionomics and/or control of such so-called pest mosquitoes as salt marsh and floodwater mosquitoes, rice-field mosquitoes, and Arctic mosquitoes in Alaska. Today, there are 20 organizational units of the Service engaged in, or supporting, research on mosquitoes and their control.

## Research Grants

In the National Institutes of Health, the Division of Research Grants

reports that the National Institute of Allergy and Infectious Diseases was administering, as of January 1, 1963, 108 active or committed grants, totaling $1,743,167, for work in which the primary interest was arthropods (3). Of these, 25 are grants that are primarily concerned with research on mosquitoes. In addition, the National Institute of General Medical Sciences and the Bureau of State Services are each supporting 4 grants for research on mosquitoes. The 29 domestic grants for mosquito research are located in 16 states, the District of Columbia and Puerto Rico; they are supporting work at 25 different institutions which amounts to $675,411. Four foreign grants, primarily for mosquito research, are located at 4 institutions in 3 countries, and total $38,315 for the year.

A number of other NIH and BSS grants concerned with various infectious organisms undoubtedly support mosquito research, but cannot be easily classified because of the plurality of interests.

In addition to research grant support, a number of entomologists are receiving training support through fellowships and training grants. Some of these studies involve work with mosquitoes.

The Division of Research Grants expects support for research and training in this area to continue in the future. This, however, will be dependent upon entomologists developing and continuing to push investigations in needed research areas (3).

## INTRAMURAL RESEARCH

### National Institutes of Health

*National Institute of Allergy and Infectious Diseases*

Seven organizational units of the National Institute of Allergy and Infectious Diseases are, or recently have been, actively engaged in research involving mosquitoes.

Workers at the Rocky Mountain Laboratory in Hamilton, Montana, have contributed to establishing *Culex tarsalis* as the principal vector and WE and St. Louis encephalitis viruses as the principal arboviruses in the northwestern U. S. (4-9). The initial colonization of *C. tarsalis* was accomplished at this laboratory (10-13). Studies involving mosquitoes are a relatively minor activity of this laboratory and are apt to remain so in the foreseeable future (14).

In the former Laboratory of Tropical Diseases, at Bethesda, Maryland, Kilham and Woke (15) showed in laboratory experiments that the virus of Shope's Fibroma in cotton tail rabbits could be transmitted by *Aedes aegypti*. Dalmat (16) successfully transmitted Shope's Fibroma and Shope's Papilloma in rabbits by mosquitoes. Dr. W. H. W. Komp's achievements on the biology and taxonomy of mosquitoes are well known to mosquito workers (17). Other research in this unit prior to 1959 was devoted to the biology, physiology and behavior of mosquitoes with application to culture methods, disease transmission, and the mechanism of action of insecticides in mosquitoes (18-25). During 1959 this Laboratory was reorganized to form five new Laboratories, including the present Laboratory of Parasitic Diseases and Laboratory of Tropical Virology. The latter Laboratory has continued

research at Bethesda along lines of arthropod-host interrelationships (26) and it is expected that future work of this unit will be in this same general area (27).

The Middle America Research Unit (MARU) of the Laboratory of Tropical Virology, jointly sponsored by the Public Health Service and Walter Reed Army Institute of Research, has operated in the Canal Zone for about six years, functioning as a research epidemiologic unit but to date emphasizing investigations on arboviruses and histoplasmosis. The first isolation of VEE virus in Panama was made at MARU in a cooperative study with Gorgas Memorial Laboratory in 1961, and since then four human epidemics and epizootics have been studied. VEE virus is prevalent in humans in Panama. EEE virus has been isolated during 3 epizootics of encephalitis among equines (28). SLE virus has been isolated from birds (28), and Ilheus virus* from mosquitoes, as well as other viruses such as Guaroa. Other studies have shown that lizards may serve as reservoirs for EEE (29). Since May 1962, MARU has been investigating the epidemiology of a severe febrile illness with hemorrhagic manifestations in Beni Province, Bolivia. More intensive studies are now in progress (28).

At the present time mosquito research in the Laboratory of Parasitic Diseases is limited to investigations of the development of filariids, using both conventional and electron microscopy (30).

At the Columbia, South Carolina, station of the Laboratory of Parasite Chemotherapy, studies have been directed toward determining the susceptibility of native anophelines to foreign and domestic human malaria, including the comparative infectivity of specific strains of *Plasmodium* species to various anophelines, and the sporonticidal effects of various antimalarial drugs. Strains of *P. falciparum* resistant to antimalarial drugs have been studied in *Anopheles quadrimaculatus*. *A. freeborni* and *A. albimanus* (31). Other studies involve the transmission of viruses alone or in combination with *Plasmodium* species by *Anopheles* species, *Aedes aegypti* and *Culex quinquefaciatus*. Semliki Forest virus (32), SLE virus and encephalomyocarditis virus in combination with P. *gallinaceum* have been studied. Infection of the immature forms of these mosquitoes with these viruses have also been investigated (33). This station is currently in the process of being discontinued and the personnel assigned to other locations. Presumably, similar activities will be pursued at these other stations in the future (34).

Studies on various aspects of simian malaria and the effectiveness of antimalarial drugs are being conducted at the Chamblee, Georgia, station of the Laboratory of Parasite Chemotherapy. Three strains of the simian malaria *P. cynomolgi,* have been passed successfully by mosquito bite from monkey to man, and monkey to monkey. Two of these, *P. cynomolgi*—B and M strains, were also passed by mosquito bite from man to man and man to monkey (35). The transfer of *P. cynomolgi* was with *A. quadrimaculatus.*

*Note Annual Rpt. of Gorgas Memorial Laboratory for 1960—page 3. Ilheus virus identified by GML in 1960 during a cooperative study with MARU in which GML furnished mosquitoes and sera for MARU's laboratory tests.

Methods have been developed, using the fluorescent antibody technique, to demonstrate one-day and older tissue parasites of various species of malaria (36). Work is now in progress with seven species or strains of simian malaria parasites, as well as two human and one bird species (37). Studies along present lines will continue for the forseeable future.

A Far East Research Unit of the Laboratory of Parasite Chemotherapy is working cooperatively with the U. S. Army Medical Research Unit and the Malayan Institute for Medical Research in Kuala Lumpur, Malaya, on the ecology of monkey malaria in that country. *Anopheles hackeri* and *A. leucosphyrus* have been found to be natural vectors of simian malaria in Malaya (38, 39). *A. leucosphyrus* is also a vector of human malaria. Four, and perhaps 5, new species of simian malaria parasites have been found during these investigations (40-42), which are expected to continue during the next two or three years (43).

## Bureau of Medical Services

### *Division of Foreign Quarantine*

The Division of Foreign Quarantine of the Bureau of Medical Services is the organizational unit of the Public Health Service responsible for quarantine enforcement. As a part of that activity, control of *Aedes aegypti* is being carried on continuously in international airports and dock areas of the yellow fever-receptive area in southern United States, Puerto Rico, and the Virgin Islands (44). More than 100 international traffic areas are being covered. Disinsection is required in about 30,000 aircraft of about 65,000 that arrive annually in commercial traffic. Representatives of this Division actually apply the disinsection treatments to approximately 20,000 arriving aircraft annually (45); this is in addition to the in-flight applications made by airlines. In the fall of 1962 two adult *Aedes albifasciatus* (native to South America) were taken in a light trap at Miami, Florida (46). *Aedes vexans nocturnus* were taken in a light trap in Honolulu in January, 1962. This suspected vector of Japanese B. encephalitis has become distributed throughout Oahu and the neighboring island of Kauai (47). In addition, *Culex tritaeniorhyncus summorosus* and *Mansoni uniformis* were found on Guam in May of 1962 (48). The Division of Foreign Quarantine plans to continue its present activities indefinitely into the future (49).

## Bureau of State Services

### *Arctic Health Research Center*

Workers of the Arctic Health Research Center at Anchorage, Alaska, accomplished a survey of mosquito species present in Alaska during the 1950's. Twenty-eight species are now known from Alaska, 27 of which are believed to have only 1 generation a year (50, 51). The species of *Anopheles, Culex,* and *Culiseta* overwinter as inseminated females that have not taken a blood meal, whereas the *Aedes* species overwinter in the egg stage. Twenty-six species are human biters and 10 are considered major pests. Other previous activities of this unit included the development of small-scale control techniques and equipment (52, 53) for use against adult mosquitoes, and a study of the effects of DDT on fish and fish-food organisms.

In the latter it was found that recommended dosages were harmless to fish when properly applied. Future activities of this Center will involve studies on the relationship of mosquitoes to human diseases in the Arctic and Subarctic, with particular emphasis on the arboviruses (54).

***Communicable Disease Center***

The remainder, and most, of the work on mosquitoes by the Public Health Service is being done in units of the Communicable Disease Center.

Over a period of 16 years, beginning in 1946, the Training Branch of CDC has taught classes in vector control for over 10,000 students in 35 states (55, 56). Courses have been held cooperatively with the Northeastern, California, Florida, Gulf, Illinois, Oregon, Utah and Virginia Mosquito Control Associates (57). Most of these trainees received 4 CDC Training Guides —Insecticides for the Control of Insects of Public Health Importance (58), Insecticidal Equipment for the Control of Insects of Public Health Importance (59), Mosquitoes of Public Health Importance (60) and Survey and Control of Mosquitoes of Public Health Importance (61). Ten pictorial keys and 4 pictorial quizzes are available for free distribution in "reasonable quantities". Ten film strips dealing with mosquito identification and mosquito larval habitats are available. Twenty motion pictures are available on free, short-term loan, the more important of which are Organized Mosquito Control, Mosquito Survey Techniques, Health Hazards of Pesticides, Biology and Control of Domestic Mosquitoes, and Arthropodborne Encephalitis — Its Epidemiology and Control. The Training Branch expects to continue its training activities relating to mosquito control and research, including the production of manuals and motion pictures, indefinitely into the future (57).

A number of significant accomplishments have been reported by the Laboratory Branch in its work on the encephalitides. Among the "firsts" reported by this unit were the isolation of EE virus from *Culiseta melanura* (62); WE virus from *C. melanura* and other mosquitoes in the eastern U. S. (63, 64); SLE virus from *Culex pipiens* in Kentucky (65) in cooperation with the CDC Technology Branch; and SLE virus from *Culex nigripalpus* in Florida last year (66). Viruses of the Bunyamwera group of arboviruses have been isolated on numerous occasions from mosquitoes in Florida, Alabama and Indiana. *Anopheles crucians* is the principal species involved, but isolations have also been made from *A. quadrimaculatus, Psorophora confinnis, Culex nigripalpus* and *Mansonia perturbans* (67). The vector potentials of numerous mosquito species for EE, WE, and SLE have been determined in the laboratory (68-70). Current activities include laboratory and field investigations on the ecology of the encephalitides. These studies will be continued in the future, with special attention to the Gulf Coast area from Florida to Texas and may include experimental control of EE and WE infections in wild bird populations (71).

The majority of the work on mosquitoes in CDC is being done by units of the Technology Branch. Its Toxicology Section, headquartered in Atlanta, Georgia with field stations at Wenatchee, Washington, and Phoenix, Arizona, has been conducting, and is continuing, studies on the health hazards as-

sociated with the use of pesticides, including their use in a variety of mosquito control procedures (72-76). The most recent work of special interest to you was the human volunteer experiments which evaluated the safety of the use of DDVP vapors for the disinsection of aircraft (77) and the safety of the use of DDVP vapor dispensers in occupied houses for malaria control (78). In addition to its studies on conventional pesticides, this Section is now studying the health hazards of selected chemosterilants (79). In the future, the Section will continue to evaluate the hazards of pesticides which may be considered for use in mosquito control operations (80).

The State Aids Section of the Technology Branch, headquartered in Atlanta, Georgia, carried out the recently concluded *Aedes aegypti* eradication pilot project in Pensacola, Florida, (81) and during the past several years has conducted extensive *Aedes aegypti* surveys to determine the distribution and density of infestations in the U. S. (82-85). This Section also is currently responsible for discharging the Service's responsibilities with regard to water resources and management, including the review of plans for reservoir preparation and maintenance procedures to minimize mosquito production on water impoundments. Cooperative studies with the Agricultural Research Service of the U. S. Department of Agriculture in the Milk River Valley of Montana demonstrated that improved soil and water management practices for certain types of irrigated hay meadows will eliminate mosquito production and increase crop yields 5 to 10 fold (86). Studies on waste stabilization lagoons as a method of sewage treatment have shown that mosquito breeding in such lagoons is associated with the presence of vegetation, and that mosquito production is not a problem in ponds that are adequately designed and maintained (87). The Service recently took the lead in organizing a working group of representatives of various Federal agencies that subsequently became the Subcommittee on Vector Control of the Inter-Agency Committee on Water Resources (88). Future activities of the State Aids Section will include a continuation of mosquito control associated with cooperative Communicable Disease Control Demonstrations (89) with State and local Health Departments (90) and consultation services.

The Encephalitis Section of Technology Branch, headquartered in Greeley, Colorado, with field units at Bakersfield, California; Wenatchee, Washington; Plainview, Texas; and Taunton, Massachusetts, has been conducting research on the natural history and control of arthropod-borne encephalitis (91) and studies on mosquito problems associated with the development and utilization of water resources (92). Significant contributions have been made on the ecology of WE and *Culex tarsalis* (93-105) and the residual effectiveness of mosquito larvicides and adulticides under a variety of conditions (106-112). Intensive larviciding within areas as large as 50 square miles in California, Washington, and Texas failed to reduce adult *C. tarsalis* populations or encephalitis transmission rates even though the larval populations in the treated areas were effectively reduced (113). Flight range studies showed that adult *C. tarsalis* were infiltrating the treated areas from untreated areas several miles distant (114). Current studies are concerned with ecology and transmission of encephalitis viruses, especially in connection with WE

and *Culiseta inornata* at higher elevations in the Rocky Mountains and with EE and *C. melanura* in the northeastern U. S. In the future it is planned to continue and intensify the current ecological investigations aimed at obtaining sufficient information about the hosts, agents, vectors and reservoirs of encephalitis viruses to develop practicable measures for controlling or eliminating the diseases (115).

At the Technical Development Laboratories of Technology Branch, in Savannah, Georgia, research and development on the use of insecticides and application equipment have been in progress for almost 20 years. Most of this effort has involved work on mosquitoes and their control. A major portion of the current activities is in support of the malaria eradication program of the U. S. Agency for International Development and is financed by a contract between that agency and CDC. The more recent developments of interest include the use of DDVP for aircraft disinsection—a study that is now going into the final phase of in-use testing in commercial and military aircraft (116-121); the development of solid formulations of DDVP for use in occupied houses in malaria eradication (122-128)—a small two-year experiment with this technique is nearing completion in Africa and a large-scale experiment is also in progress in Haiti; the evaluation of a number of new organophosphorus and carbamate compounds for adult mosquito control (129-133); the use of solid formulations of DDVP to control mosquitoes in catch basins (134, 135); and the development of a simple rubber disc (136-138) for insertion in the nozzle tip of hand sprayers which effectively regulates the discharge rate and pressure, resulting in the saving of labor in pumping up of the sprayers, more uniform and less wasteful application of insecticide and less erosion of the nozzle tips. It is expected that future activities of the Technical Development Laboratories will continue along present lines.

Perhaps it is fitting to end this presentation with a discussion about the same mosquito with which it was opened—*Aedes aegypti,* the urban vector of yellow fever. The following is an excerpt from the "Message from the President of the United States Relative to a Health program, to the House of Representatives on February 7, 1963," which appears in the House of Representatives Document No. 60: "A problem of particular significance in the Western Hemisphere is that of yellow fever. Many countries of the Americas have conducted campaigns to eradicate the mosquito which carries yellow fever, but the problem of reinfestation has become a serious one, particularly in the Caribbean area. We have pledged our participation in a program to eradicate this disease-carrying mosquito from the United States, and the 1964 budget provides funds to initiate such efforts. This will bring this country into conformity with the long-established policy of the Pan American Health Organization to eliminate the threat of yellow fever in this hemisphere."

If this program is initiated, it is expected that it will be carried out by the Communicable Disease Center, in cooperation with the State Departments of Health of the affected States.

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