ARTICLES

THE ERADICATION OF *ANOPHELES ALBIMANUS* IN PUERTO RICO—AN ECOLOGIC DISCUSSION

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PART II

III. Environmental Factors Affecting Operations

Success in eradication requires that there be protection against infiltration from outside areas during and following eradicative activities and that the unit and total area of species occurrence not be too great. Some domesticated species are biologically self-limited to isolated pockets (unit areas) composed of urban areas, thus simplifying the mopping-up task, preventing infiltration, and limiting the size of the self-contained, useful-unit of operation. With many other species, including *An. albimanus,* island situations generally are necessary to avoid infiltration in the form of direct flight from outside areas. This factor, as well as the hazard of re-introduction by land, air and water transport, would make impossible the eradication of *An. quadrimaculatus* from individual municipalities, counties or states in this country which are bordered by other "quad" breeding terrain.

The island of Puerto Rico is about 100 miles long and 30–35 miles wide. Nearby are six small islands totalling about 100 square miles in area, which belong to Puerto Rico. Aside from these, no land is within some 50 miles of Puerto Rico. The total project area of 3,534 square miles is somewhat larger than might be desired from the standpoint of economy in cost of eradication, but does not *per se* make the undertaking impractical.

The feasibility of eradication in Puerto Rico is enhanced considerably by the mountainous divide running in an east-west direction, forming the long axis of the island. The elevation of this divide, which ranges from 2,000 to 4,300 feet except where it slopes into the sea at its termini, is not considered a barrier against production or flight of the species by virtue of sheer elevation above sea level. Ruggedness of slope and dense shading by tropical rain forests resulting from greatly increased precipitation on the mountain sides do, however, largely inhibit production within at least two miles of the divide on either side. In the remainder of Puerto Rico, the species may be found girdling the island in a nearly continuous belt. Production is greatest in the flat coastal plains nearest the sea, diminishing rapidly toward the mountains, except in tongues formed by stream valleys.

Tactically, this rugged backbone permits reducing the average width of front to something less than half the width of the island. An offensive could advance laterally along the shore line with one flank protected by the sea and the other by the mountains. The primary front (in flat plain lands where breeding surfaces and species abundance are greatest), rarely would exceed five miles in width, and the secondary hilly front five to 15 miles. In the southwestern corner of the island, the desert-like Lajas Valley between the hills and the sea would provide a starting point in the form of an easily developed buffer zone furnishing protection against infiltration from the rear. The main buffer zone straddling the long axis backbone would be occupied by a light holding force as insurance against cross-divide infiltration into the sanitated coastal zone.

The present human population of Puerto Rico is approximately two million, a density of nearly 600 persons per square mile. This is concentrated in the coastal plain areas. Such a high density of human population in the com-

bat zone can only impede mobile tactical operations in either insect or human warfare. One of the major problems created is the necessity for disinsectizing the heavy stream of vehicles passing from unclean into clean zones at all hours of the day and night. The political complications alone which might arise from inept management of road blocks deserve more than passing notice.

On the other hand, the great density of human population has caused the elimination of significant wild life values on the island, and hazards in this quarter resulting from the application of insecticides should not be encountered.

Some agricultural hazards are present. Principally, these involve possible harm to the beneficial insects of sugar cane culture, to the consumers of refined sugar, sugar, sugar by-products and sugar on the stalk, and to milk consumers, which might result from the repeated application of heavy dosages of DDT. Rice cultivation is virtually absent in Puerto Rico, sugar being the only significant irrigated or wet land crop. Fortunately, many of the largest and most accessible breeding places in Puerto Rico comprise cut-over mangrove swamps and the margins of uncut mangrove swamps. These possess no significant wild life, agricultural or other economic value other than the wood itself which is used for charcoal making.

IV. Hazards of Reintroduction

Following eradication, the species could be transported to Puerto Rico in the adult stage by airplane or boat, or less likely in the immature stage by boat. Eradicative operations would be justified only following field observations indicating that *An. albimanus* never would be reintroduced, or that this would happen rarely and could be coped with readily.

Administratively, adequate safeguards against introduction by airplane are provided by the foreign quarantine regulations of the U. S. Public Health Service. Actually, some increase in inspectorial service, and improvement in disinsectization practices by airplanes before landing would be warranted to insure maintenance of eradication. Baggage and cargo compartments are especially suspect. The picture is complicated by the use of minor airports by chartered airplanes engaged in international travel.

Little is known of the hazard offered by small inter-island vessels which visit other West Indian islands and stop at many ports in Puerto Rico. Many of these are sailing vessels on unscheduled runs. Entomological inspection as a foreign quarantine activity has not been available at ports other than San Juan. Close entomological surveillance to evaluate this hazard should precede eradicative operations. Perpetual entomological inspection of all inbound water and air transport from *An. albimanus* areas probably would be indicated as a precautionary measure. This should include military and naval surface vessels and airplanes.

The second and most vital line of defense would be an entomological intelligence service for the prompt detection of an enemy landing at any of the critical ports of entry, and a skeleton security force to repel the invasion. The role of quarantine is to make reinvasion an improbable happening, but catastrophe could come only if facilities for repelling the rare invasion were too little and too late. The financial requirements for such an intelligence and skeleton security force probably would range between $50,000 and $100,000 in annual cost, assuming able management of the work and freedom in the selection of personnel. The knowledge and skill acquired in island-wide eradication would be important assets which would help to insure adequacy of protection with a small intelligence and security force.

V. Design of Eradication Operations

The basic justifications for eradicating *An. albimanus* in Puerto Rico are the incalculable economic and social costs of malaria over the past four centuries, the greater economy of eradication as compared with the cost of perpetual malaria control, and the apparent infeasibility of

malaria eradication due to the certainty of frequent reimportation by human carriers from other West Indian Islands and South America.

Ecologic and insecticidal factors favoring the feasibility of eradicating the species in Puerto Rico offer promise that this goal may be achieved at some future time, provided island-wide operations are preceded by (1) further bionomic studies to reduce the number of lacunae of major significance; (2) a successful demonstration of *albimanus* eradication on a smaller scale under reasonably comparable conditions; and (3) a carefully prepared plan of operations which utilizes these additional data and experience. The author is of the opinion that island-wide eradication undertaken without these prerequisites would invite certain failure, and that final decision as to feasibility of the project should not be made at this time.

The case for "pilot plant" eradication is especially strong. Such a project would provide data for more accurately estimating the cost of larger scale operations and would serve as a proving ground for technologic and other operational procedures. Properly controlled, it would tend to resolve into one conclusive answer the effect of many obscure biologic factors. The key principle of eradication is the elimination of the last specimen. Bionomic studies mainly reveal the environmental responses of most members of the species, or representative members, rather than the abnormal manifestations of the hundred millionth individual on which the success or failure of eradication may rest. Legislative appropriations and authorization for the large scale operation probably can be secured only by prior successful demonstration.

A demonstration area is available in the Island of Vieques, one of the six islands previously mentioned which belong to Puerto Rico. A preliminary analysis of the feasibility of eradicative operations on this island was made by Henderson et al.[13] in February, 1947, and a more complete study in June, 1947, by Andrews et al.[14] Space prevents presenting a complete description of Vieques Island but some information from the author's notes is given below. The island lies beyond flight range of Puerto Rico, is 21 miles long and three to four miles in width. The cost of an eradication project is estimated at $100,000 to $200,000. *An. albimanus* occurs in reasonable abundance and may be found in a variety of breeding places, including small streams, mangrove swamps and wet pasture lands. The inherent difficulty of eradication is somewhat less in Vieques than in the main island of Puerto Rico. This is due principally to the absence of irrigated sugar cane as a complication and to the large cattle population which theoretically favors the effectiveness of adulticiding. Production may be found, however, in association with upland sugar cane production and in this respect conditions on the main island are simulated.

Although secondary reliance might be placed on adulticidal measures wherever they give promise of providing substantial aid toward eradication, bionomic considerations dictate selection of larviciding as the main weapon. Swamps, marshes, alkali flats and wet meadows could be treated most effectively by airplane. Linear situations including ditches and small streams should be treated by hand, using the air-borne mist technique. Power operated ground equipment could be used to a limited extent for some breeding surfaces. The insecticide used would be DDT and/or its more recently developed competitors. Dosages applied to most breeding surfaces could be increased markedly over the maxima permissible where wild life values exist. This advantageous circumstance, augmented by the application of two or more closely spaced treatments within each breeding

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[13] Henderson, J. M., Palacios, L. D., and Stephens, P. A. Feb. 1947. Unpublished Memoranda of Dep't of Health of Puerto Rico.

[14] Andrews, J. M., Tetzlaff, Frank and Trapido, Harold. Report on the Feasibility, Procedure and Cost of *Anopheles albimanus* Reduction in Vieques, Puerto Rico. July 1947. Unpublished.

cycle, should greatly increase the effectiveness of larviciding as an eradicative technique.

The high kill which it is believed can be obtained by larvicidal measures, and the more moderate kill of imagoes which probably can be obtained even by a combination of adulticidal measures, invites speculation as to eradicative procedures.

Theoretical concepts of preventive medical practice commonly favor the comprehensive attack. When these are applied to the present situation of insect warfare, they encourage placing great attention on adulticidal measures, for the purpose of strengthening this weak link in the eradicative attack against *An. albimanus*. In support of this principle are the facts that eradication solely by anti-larval measures requires that (a) the measures be continued until the last surviving gravid female has died from natural causes, and (b) the effectiveness of anti-larval measures plus the natural death rates of immature and mature stages will be great enough to bring this about in a reasonable period of time.

The military scientist on the other hand, favors exploiting the enemy's weakness (i.e., his own strength) at the expense of other directions of attack. In this way, superior striking power at the point of intensive attack is achieved. Other offensives are mounted only when there is a surplus of strength. In the tropics, the competent tactician in insect warfare subscribes to this principle for its intrinsic worth and for the added urgency of simplifying operations to conform to the capabilities of the project force.

In the current instance an average reduction of 95% in larval population per application of DDT larvicide probably can be expected, especially in view of the high dosage rates contemplated. (In many breeding places 100% kill will be obtained, but in others some larvae will escape, and a few minor breeding places may be overlooked). Two applications on adjoining days theoretically would accomplish a cumulative reduction of 99.25%, a survival rate of 0.75%.

An intensification of larviciding to increase the average kill from 95% to 96% would effect a further reduction of 80% in the survival rate (from 0.75% to 0.16%). Superficially, this marginal increase in larvicidal effectiveness would have the same ultimate effect as a comprehensive complementary attack against the adult resulting in an 80% reduction in the adult population at large. The fact that the single gravid female may be the future source of several hundred larvae does not alter this theoretical principle where larviciding is to be recurrently practiced throughout the life span of the last surviving gravid female. Other considerations, however, may justify prosecuting adulticidal methods, even though these may be far less effective than larviciding. A reduction of 50% in the adult population at large for example, might possibly cut in half the life span of the last surviving gravid female. In general, adulticiding will prove desirable only if the project management and organization are able and adequate enough to prosecute both activities without injury to the larviciding program. (The percentages given above are hypothetical, and only partly supportable by experience.)

Present techniques for sampling populations of *An. albimanus,* although reliable for malaria control purposes, are far from sensitive enough to meet optimum standards in eradication. Adult collections rather than larval possess greatest significance as a measure of interim progress and final success or failure in eradicative operations against this species. The principal adult collecting devices are the animal bait trap and the electric light trap. These are especially insensitive in recording the presence of very sparse populations of *An. albimanus*. Since a few remaining survivors may escape detection, operational failures may be concealed until substantial recovery of population has taken place. This weakness may be correctable in part by improved collecting procedures, but its fundamental basis is the sylvan-like

behavior of the adult. Hand catching of specimens at night from habitations, stables and pastured cattle may prove desirable. Inspectorial activities for the collection of immature and mature specimens occupy a role of high importance in eradicative operations.

Studies which should be undertaken concurrently with the Vieques demonstration toward evaluating the feasibility of eradication in the main island of Puerto Rico include:

1. Determination of safe dosages of DDD as a substitute for DDT in wet dairy pastures and some other situations.
2. Intensive inspection of small inter-island sailing vessels for mosquito specimens.
3. Effect of DDT or related insecticides at varying dosages on sugar cane—economic, entomological, botanical and pharmacological aspects.
4. Further studies on the day-time resting places of *A. albimanus*.
5. Entomological collections of *A. albimanus* along the backbone ridge of Puerto Rico and in the Lajas Valley area toward evaluating buffer zone properties.
6. Safe dosages of DDT or related insecticides where snail-eating minnows are present in streams (to avoid increasing the schistosomiasis hazard).
7. Precipitin tests of blood-engorged specimens of *A. albimanus* as an aid in planning and determining adulticidal technics.
8. Studies on the possible estivation of immature stages of *A. albimanus*.[14]

VI. Remarks

A plan for eradicating *A. albimanus* in Vieques and of performing certain of the above studies has been under consideration by the Department of Health of Puerto Rico and the U. S. Public Health Service, Communicable Disease Activities. An extended survey was made in 1947 by Andrews and others,[14] in company with Puerto Rico Department of Health and other Insular officials. Subsequently, plans for work in Vieques were interrupted due to change in land ownership, but they are applicable in principle to other small islands.

The program as outlined would involve operational, inspectorial and investigational activities. It is believed that *A. albimanus* eradication on Vieques or a comparable island is feasible in spite of incomplete information regarding the adult behavior of this mosquito. Such a program should provide critical information regarding the technical feasibility and probable costs of island-wide *A. albimanus* eradification in Puerto Rico.

VII. Acknowledgment

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Mr. Henderson was resident in Puerto Rico for 3½ years. From November 1940 to March 1942 he was Acting Head of the Department of Public Health, School of Tropical Medicine, San Juan, P.R. From March 1942 to February 1944 he was in charge of operations in the West Indies on military base malaria control activities of Malaria Control in War Areas, U. S. Public Health Service, with rank successively of Major and of Lt. Colonel. From December 1942 to February 1944 he was senior member of an Army Malaria Control Board attached to G-4, Commanding General, Antilles Department, with jurisdiction over all Army malaria control through the West Indies, Trinidad and the Guianas. From February 1944 to March 1946, while serving as Chief, Engineering Division, Malaria Control in War Areas Headquarters, Atlanta, Ga., Mr. Henderson maintained general supervision over military base malaria control in Puerto Rico and Jamaica, B.W.I. He is now Professor of Sanitary Science, Columbia University, School of Public Health.

Mr. Henderson's most recent visits to Puerto Rico were as Consultant on Malaria Control to the Puerto Rico Department of Health, February 1947, and as Principal Investigator of a National Institute of Health Research Grant Study of the bionomics of *Anopheles albimanus*, September 1947.