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METHODS DIRECTED AGAINST ADULT MOSQUITOES IN THE CONTROL AND ERADICATION OF MALARIA

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Destruction by Hand

The systematic collection of mosquitoes in dwellings as a prophylactic measure against malaria originated in the Canal Zone according to LePrince and Orenstein (1916). There it was adopted as a standard procedure following its successful use in a temporary camp at Cocoli in 1908. Universal application has been found for modifications in the technique of collecting mosquitoes with a cylindrical glass tube, about 4.5 inches long and one inch in diameter, in the closed end of which were located cut up rubber bands saturated with chloroform. The capture of live specimens has been facilitated by the use of glass tubes having an inward opening funnel fused in one end and a suction tube affixed in a cork at the other end.

LePrince (1926) stressed the value of destroying anopheles in dwellings, particularly when permanent measures temporarily fail, and noted that their resting habits frequently make the fly-swatter and collecting tube effective in the reduction of malarial transmission even in unscreened buildings.

Reitler estimated that malaria was reduced to one-fifth on a construction project in Palestine largely through the collection of female *A. superpictus* Grassi and *A. sergenti* Theo. from resting places among dark woolen garments. Collections were made with test tubes wetted on the inside with kerosene.

In Europe, Hackett (1937) remarked that programs for collection of adults were unsuccessful in groups of individuals not under rigid discipline because there was no way to compel villagers to capture mosquitoes and a few recalcitrants might render the whole campaign ineffective.

Mosquito collections in houses enabled Davey and Gordon (1933) to reduce to a mathematical formula the relationship between infected anopheles densities and the possibility of inoculation with malaria from different species or in different localities.

Nets

Since ancient times protection has been obtained from the bites of mosquitoes by the use of nets. As an emergency measure they have been used as bed nets, head nets and as accessory parts of other devices.

Russell and Nono (1934) considered it likely that nets are the most important defense against malaria in the Philippines where permanent screening is out of the question because of the loose construction of rural habitations. These authors found that the locally made sinamay netting of about 16 by 20 mesh per inch with fibers averaging 0.13 inch diameter would exclude all anopheles and most other mosquitoes. Bed nets illustrated in this report were made completely of netting for maximum circulation of air. Marzinovsky recommended bed nets with cloth tops to keep dust from falling on the sleeper and cloth bottom edges to exclude scorpions and snakes.

The use of nets for protection from *A. gambiae* was urged by Thomson in Southern Rhodesia and by Thornton in Natal. Gater concluded that in Malaya, 22/23 mesh cotton net was adequate to exclude anopheles. In Africa, netting of 25/26 mesh cotton afforded protection from *A. gambiae* and *A. funestus,* according to J. Y. Brown (1934) and to Hargreaves (1936). Covell (1931a) pointed out that the mosquito netting supplied to the British Army in India is 25/26 mesh woven cotton thread

of 25,200 yards to the pound. Copper wire screening in the 16/16 mesh, 28 S.W.G., recommended by LePrince and Orenstein (1916) for the Canal Zone, was found to possess the maximum safe aperture for use in Africa by Davey and Gordon (1938). Mulligan and Majid (1932) stated that apertures somewhat larger were satisfactory for India. Earle (1932) judged that 12-mesh copper of 0.015 inch diameter wire was probably the best screening material for Puerto Rico.

Traps

Traps providing an attractive resting place for adult mosquitoes have been extensively used in India. Those reviewed by Covell (1931a) have been supplemented by the feather duster and earthen pot traps described by Gore (1937a, 1937b). Russell and Santiago (1934) devised a box-like trap for anopheles which had a layer of soil one inch thick held in place on the inside walls and roof by 16-mesh screening. A drip-can on the roof kept the soil moist. The trap bottom was open and the one end not boarded up was partially closed at night by a black cloth which hung to within 6 inches of the ground. The box was placed directly on the ground and collections were made with glass vials in the morning. The smallest effective trap of this type used in the Philippines was 2 feet wide, 2 feet high and 3 feet long.

In the Orient human-baited traps have been effectively used. Manalang (1931) captured females of *A. funestus* Giles (*minimus*) in a wire screen cage baited with a man sleeping under a mosquito net. The collector did not risk contracting malaria and mosquito collection was made relatively easy. Urbino (1936, 1938) and Ejercito (1938) also reported the use of man-baited traps to determine the density of *A. minimus* var. *flavirostris*. Gater (1933) found that a double bed net, of which the outer had openings that were closed with flaps at intervals during the night, was many times more effective than hand catches in the collection of Malayan anopheles.

In Panama a V-shaped ridge of screening with a slit cut in at the apex enclosed in a screen wire housing was used with success by Bath (1931) to entrap mosquitoes attracted to human scent. The unit was mounted at the top of a window or in the wall of a building. Mosquitoes entering the slit were confined between the ridge and housing screens. In the West Indies, South and Central America, animal baited traps have reached their highest state of development. Magoon (1935) illustrated a stable trap for the capture of anopheles mosquitoes in Jamaica. Earle and Howard described the portable stable trap employed in Puerto Rico and stressed the value of studies of mosquito densities in the direction of control work. Earle (1934, 1937) used animal baited traps for a number of years to determine the feeding preferences of anopheles and to trace the reduction in density of *A. albimanus* Wied. resulting from mosquito control measures. Carr, Melendez and Ros, by means of calf-baited traps, found *A. albimanus* most abundant in the areas of greatest malarial incidence in the Province of Havana. Pereira Barreto captured *A. darlingi* var. *paulistensis* and other Brazilian anopheles attracted to a horse, and Gabaldon illustrated the burro-baited stable trap used in Venezuela.

In a comparison of animal-baited and mechanical mosquito traps in Panama, Curry stated that the mechanical suction fan light trap was notably inefficient in obtaining information as to density of flights. A portable muslin and netting cage which could be suspended over an animal by cords was devised by Shannon (1939), principally for the capture of non-anopheline mosquitoes. In the capture of *A. maculipennis* emerging from hibernation quarters in Central Russia, Khelevin (1938) employed glass plates covered with a mixture of one part castor oil and two parts colophony.

In the eastern United States electric light traps have been widely used for sampling mosquito populations. The evolution of the New Jersey light trap from an illuminated sugar can to electric fan suction

models equipped with time clocks can be traced in the reports of Headlee (1932). In these traps a vertical sheet metal cylinder is covered by a conical roof spaced some distance above its upper end. The attractive light source is located directly under the roof which acts as a reflector. An electric fan is mounted in the upper portion of the cylinder and a screen funnel emptying into a cyanide jar is placed below the fan. Insects attracted to the light are sucked through the fan and are killed in the cyanide jar. The value of these instruments in evaluating anti-mosquito work has been demonstrated by Mulhern (1940). Bishopp, Cory and Stone (1933), in a mosquito survey of the Chesapeake Bay section, observed that *A. quadrimaculatus* and *A. punctipennis* did not enter these light traps in proportion to their relative abundance. In Florida, Bradley and McNeel (1935) traced seasonal variations in the abundance of *A. crucians* and other mosquitoes by means of New Jersey traps. Carnahan (1939) found about 6 per cent of all specimens collected in these light traps near Miami, an airport of possible entry of exotic species into the United States, were *A. crucians* Wied., *A. walkeri* Theo., *A. quadrimaculatus* Say and *A. atropos* D. and K. represented in that order of abundance.

Johnson (1937) captured *A. walkeri* in abundance in Tennessee with similar traps in an area where hand catches were negative to that species. As various colors were tested the attractiveness of the light increased through the visible spectrum from red to violet.

Infra-red and photographic red light did not attract anopheles but ultra-violet did so, slightly.

Reports of mosquito collections by means of New Jersey type light traps include Botsford and Turner (1933), Stearns, McCreary and Newhouse (1933), McCreary (1939) and Shields (1938). Storage battery operated devices patterned on these traps have been used by Butts (1937) in New Jersey and in a Works Progress Administration Project in Delaware (1939).

Sprays

Previous to the widespread adoption of pyrethrum in kerosene oil sprays for the destruction of adult mosquitoes, Mansell (1930) recommended a spray composed of 1 per cent pure carbon tetrachloride, 2 per cent methyl salicylate in second quality kerosene with the addition of one-fourth pound naphthalene to each gallon, applied at the rate of 5 fluid ounces to 1000 cubic feet, and Barber (1936a) found a saturated solution of naphthalene in kerosene cheap and moderately effective.

In Africa, Thornton (1934, 1936), Booker (1935, 1936), and Ross (1936) reported campaigns against *A. gambiae* and *A. funestus* in which the systematic and efficient spraying of native dwellings with a pyrethrum spray prevented epidemic malaria in every case in which they were instituted. Huts representing a population of more than 50,000 natives were included in certain spray programs.

In Europe, Swellengrebel (1934) conducted extensive experiments on the destruction of adult mosquitoes in buildings with pyrethrum sprays. Nijkamp and Swellengrebel (1934) recommended a spray for stables which was composed of kerosene 550 cubic centimeters, vaseline oil 450 cubic centimeters, methyl salicylate 20 cubic centimeters, oil of sassafras 10 cubic centimeters and pyrethrum extract 10 grams. Spraying was considered a routine and not an experimental procedure by Schüffner and Swellengrebel (1938). These authors concluded that spraying against anopheles in a state of sexual inactivity in houses in late summer prevented from 50 to 92 per cent of the malaria that would otherwise occur in the following year.

Nabokov and Tiburskaya (1936) obtained excellent results against anopheles in daytime shelters in peat bogs near Moscow with a 10 per cent benzine extract of pyrethrum with the addition of phenyl and methyl salicylates when applied at the rate of 10 fluid ounces per 1000 cubic feet. Viktorov estimated that at least 90 per cent of mosquitoes in houses and tents were destroyed by spraying with a water solution

of soft natron soap with the addition of methyl alcohol.

In India, Sinton and Wats (1935) tested the efficiency of various insecticidal sprays in the destruction of adult mosquitoes and found that a solution of one part of a standardized concentrated extract of pyrethrum flowers (Pyrocide 20) in 19 parts of refined kerosene gave results approximately equal to those of the best proprietary brands at about half the cost. These authors stated that the spray was improved by the addition of 5 per cent oil of citronella, ½ to 1 per cent oil of sassafras or 4 to 5 per cent oil of pine. Manifold (1939) remarked that a popular formula for the spraying of huts, barracks and tents was made up of paraffin oil, second grade, 124 oz., extract of pyrethrum 2 oz., carbon tetrachloride 4 oz., oil of citronella 8 oz. and gasoline (Petrol) 22 oz.

Sprays of pyrethrum extract (Pyrocide 20) in 19 parts of kerosene yielded satisfactory results in many anti-mosquito campaigns. Chopra (1938) added one part of pine oil to the mixture; Covell, Mulligan and Afridi (1938) obtained favorable cost comparisons with temporary anti-larval measures; de Burca (1939) believed reduced incidence of malaria among troops in a cantonment followed a spray program and Russell and Knipe (1939) concluded that the weekly spraying of houses and sheds prevented malaria transmission to a marked extent. Barreto (1929) added pyrethrum to the kerosene and carbon tetrachloride spray used originally in the Rio de Janeiro yellow fever epidemic in order to destroy adult anopheles in Brazil.

In the United States outdoor gatherings have been provided temporary protection from mosquito attack by using sprays. Ginsburg (1935) reported a series of satisfactory trials of a pyrethrum larvicide spray for this purpose. In one formula an emulsion of 100 gallons of kerosene, containing extract of pyrethrum in the amount equal to 100 pounds of flowers, 6 pounds of "Gardinol" concentrated wetting agent and 50 gallons of water was diluted with 10 or 12 parts of water. Power sprayers applied the diluted material to the vegetation and as a mist in the area to be protected. In Florida, King, Bradley and McNeel (1937) obtained a high degree of mosquito repulsion in an uncleared area with pyrethrum extract, pine tar oil, oil of citronella and kerosene sprays. In a cleared area, however, none of these sprays was effective during the first mosquito flight period. The behavior of the insects suggested that they were affected chiefly upon coming in close contact with the sprayed vegetation rather than by odors carried through the air.

Among the methods used for destroying disease transmitting mosquitoes in aircraft, Symes (1937) recommended spraying the compartments immediately after departure from an airport with a mixture of 1 part concentrated extract of pyrethrum, 16 part of white kerosene and 68 parts of carbon tetrachloride. Ross (1938) described the use of aqueous base and carbon tetrachloride extracts of pyrethrum in aircraft of the Imperial Airways. Application was made with dry mist vaporizers and sprayers operated by a soda water siphon bulb containing carbon dioxide under 400 pounds pressure.

Griffitts (1933) demonstrated the ability of mosquitoes to enter the United States from Central America in aircraft and endorsed the procedure of fumigating airplanes under emergency conditions and preceding overhaul with as much as 8 ounces of hydrocyanic acid per 1000 cubic feet in the form of Zyklon discoids.

Williams (1940) outlined the procedure of the Public Health Service to prevent the introduction into the United States of mosquitoes infected with yellow fever from South American ports; to prevent the introduction of *A. gambiae* from eastern South America; and to prevent the introduction of any anopheles from the west coast of the United States into the Hawaiian Islands. The methods of spraying the fuselage of all planes from South America with a concentrated pyrethrum spray (2 grams pyrethrins in 100 cubic centimeters of light oil) as described by Williams and Dreesen (1935) and by Welch (1939) was changed to spraying the interior of the

planes at a port removed from both the infected territory and the nearest United States port. A power sprayer was especially designed with an accurate metering device and an adjustable nozzle with a pressure release to prevent dripping of insecticide.

Fumigation

Sulfur burned alone or in combination with other materials has long been a moderately effective method of fumigation against adult mosquitoes in spite of its disadvantages. Ananyan (1929) burned a mixture of dung and sulfur to drive *A. maculipennis* into box traps on the top of cow sheds in Armenia, and Clyde found that burning a mixture of equal parts of sulfur and powdered waste tobacco was an effective fumigant. To reduce fire hazard, Nabokov (1929) experimented with the generation of sulfur dioxide from sodium sulfite and sulfuric acid. He also constructed an apparatus in which the fumes from burning sulfur or tobacco on three dishes placed one above another in a metal cylinder were carried off by a pipe affixed to a conical lid.

James (1935) cleared barracks of anopheles by burning pyrethrum to drive them into a net bag mounted on a dark cloth stretched over a window. Rooms were darkened so that the trap bag was the only lighted area visible to the anopheles. The less effective fumigants, cresol and sulfur, were also used. Treillard (1934) recommended the dripping of cresol on a hot plate in fumigating against anopheles in Indo-China.

A finely ground slaked limedust impregnated with 5 to 10 per cent anabasine sulfate and applied at the rate of 5 ounces per 1000 cubic feet was effective against hibernating mosquitoes in Russia according to Kremer and Kuvichinskii (1937) and Pivovarov and Guterman (1937). Benyaminson and Nabokov destroyed hibernating mosquitoes in freezing temperatures with 2 ounces of pyrethrum dust per 1000 cubic feet, and May found vapors of hexachlorethane toxic but not very practical in the control of mosquitoes in closed spaces.

Poisons

In experiments with poisoned baits for destroying adult anopheles, Lischetti (1927) mixed honey with mercury bichloride, boric acid, arsenious anhydride, potassium arsenite or potassium cyanide. Potassium arsenite proved most satisfactory; potassium cyanide, though most active, soon lost its toxicity.

The supposed toxic effect of coumarin on malarial parasites when ingested from clover by female anopheles was not supported by experimental evidence (Mayne 1930a). Stratman-Thomas (1931) considered that any correlation between the planting of leguminous plants and reduction in malarial incidence was due to drainage necessary in growing the crop.

Repellents

Coogle (1925) repelled mosquitoes from unscreened and dilapidated houses by pressure spraying creosote at the rate of one gallon per 450 square feet of interior wall surface.

Gutzevitch and Podolyan (1935) repelled mosquitoes with smoke candles made from a mixture of 100 gm of pyrethrum powder (pyrethrin content .28 per cent), 50 oz semi-liquid wheat flour paste, 25 oz potassium nitrate, 25 oz sawdust and 50 to 70 fluid oz water. Candles about one centimeter square cut from the viscous mixture were dried and burned at $\frac{1}{2}$–$2\frac{1}{2}$ oz per 1000 cubic feet as a repellent or 1–$1\frac{1}{2}$ oz per 100 cubic feet as a fumigant.

Repellents for the protection of individuals from mosquito attack have been concocted on a rather empirical basis until recently. Bunker and Hirschfelder (1925) set forth the desirable characteristics of such substances for personal use and tested the effect on mosquitoes of most of the materials recommended in earlier literature. Twenty substances listed in their general order of effectiveness were: (1) citronellol, (2) caprylic alcohol, (3) benzyl alcohol, (4) geranyl acetate, (5) linalyl acetate, (6) amyl salicylate, (7) acetophenone, (8) oleum picis liquidae rectifactum, (9) phenyl-propyl alcohol, (10) oliver oil, (11) citronellal, (12) camphor, (13) vanillin,

(14) methyl cinnamate, (15) menthol, (16) cedarwood oil, (17) citrol, (18) coumarin, (19) beta-naphthol-ethyl ether, (20) geraniol. These authors suggested that the influence of certain atomic groups on insects might act as a guide in the search for more effective repellents. Alcohols, ketones, and aldehydes were in general more efficient than other groups. Rudolfs (1926, 1930) studied the response of mosquitoes to many of the organic compounds associated with animal and human odors and tested a large number of oils, solvents and organic compounds as repellents for non-anopheles. Gibson (1935) reported tests on several well-known repellent formulae.

Oil of citronella, one of the most effective and popular repellents, was mixed with an equal part of olive oil by Cooley and others. Freeborn found a mixture of 3 oz oil of citronella, 1 oz spirits of camphor, 1 oz tar oil, ¼ oz oil of pennyroyal and 4 oz castor oil effective against *Aedes* mosquitoes, and Manifold (1939) stated that the British army in India, Egypt and Palestine used a modification of Dover's repellent consisting of oil of citronella 18.25 per cent, camphor 1.00 per cent, cedarwood oil 9.00 per cent, paraffin duram 26.75 per cent and paraffin molle-white 45.00 per cent. MacNay (1939) recommended ½ fluid oz oil of thyme, 1.0 fluid oz extract of pyrethrum (0.2 pound of flowers) and 2 to 3 fluid oz castor oil as being effective for 3 to 5 hours against *Aedes* species.

Granett (1940) gave results of comparative tests of established repellent substances and a recently developed proprietary synthetic organic chemical mixture containing diethylene glycol monobutyl ether acetate, diethylene glycol monoethyl ether, ethyl alcohol, corn oil and perfume. Developed from tests of nearly 1000 compounds and mixtures, this repellent was found to be definitely superior to citronella and 42 representative proprietary products in lasting power and desirable accessory properties.

Deviation

In Macedonia the investigations of Barber and Rice (1935), comparing the attraction to humans of *A. elutus* and *A. maculipennis* varieties *typiens* and *messeae,* illustrated the necessity of knowing the degree to which local anopheline species are attracted to animals before judging the effectiveness of animal barriers.

In China, although *A. hyrcanus* var. *sinensis* Wied. was found to be zoophilous, Toumanoff and Hu (1935) judged deviation by animals was not complete. In the Philippines, Russell (1934) was unsuccessful in protecting a native house from *A. minimus* var. *flavirostris* by the use of four water buffalos. In Kenya, Symes (1930) showed that cattle stabled within native dwellings afforded the inhabitants little protection from *A. gambiae* and *A. funestus.*

In Argentina, precipitin tests by Davis and Shannon (1928) showed 50 per cent of *A. pseudopunctipennis* taken in houses to have fed on man. In Venezuela, Hill found *A. albimanus* fed on man in large numbers and in Puerto Rico precipitin tests confirmed observations that *A. grabhami* preferred animal blood to that of man. In Mexico, the majority of *A. pseudopunctipennis* captured in houses in Temixco by Vargas (1938) contained human blood.

In Canada, Hearle observed that *A. maculipennis* attacked animals in preference to man on the prairies; and in the United States, Boyd (1930d) suggested (from precipitin tests on blood from anopheline stomachs in North Carolina) that the nocturnal presence of cattle in the vicinity of dwellings was associated with reduced malaria and that this was probably accomplished by a diversion of *A. quadrimaculatus* from man to cattle. Christophers and Missiroli (1933) judged that in general this use of cattle will be confined as a practical measure to conditions where the cattle form an integral part of an agrarian scheme. Hackett, Russell, Scharff and Senior-White (1938) considered deviation the only naturalistic measure showing promise of success or worthy of the expenditure of public funds.