Control of Mosquitoes in California Rice Fields

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Since its introduction in 1912 at Biggs, Butte County, California, (Freeborn 1917) commerical rice growing has created one of the major mosquito control problems in the state. Prior to that time relatively few mosquitoes were found in the areas of the Sacramento Valley where rice is now grown. Since that time they have become so numerous that they are a serious pest not only in the communities immediately adjacent but also in those at some distance from the rice fields.

Present Problem.—Within the last 10 years the rice acreage has approximately doubled, 412,000 acres[2] were planted in 1953. Where it was chiefly confined to the rural areas of the Sacramento Valley it is now being planted in the suburbs, and the acreage in the San Joaquin Valley is rapidly increasing. Not only has the pest problem been multipled many times but the health hazard has likewise increased.

Anopheles freeborni (Aitken) the most prevalent mosquito in the rice fields is also the principal vector of malaria in California.[3] Although relatively few cases of malaria have occurred within recent years the great numbers of this mosquito produced in the rice fields constantly present a potential hazard to the health of the people in the area, (Furman 1953).

Culex tarsalis (Coq.) is considered to be the principal vector of encephalitis in California (Reeves 1953). In the 1952 epidemic (Stead & Peters 1953) there were 804 human cases of encephalitis,[4] primarily in the San Joaquin and Sacramento Valleys.

Cultural Practices And Ecology.—The cultural practices employed and the ecology of the rice field areas present optimum conditions for mosquito breeding and at the same time make control difficult. Early in the spring prior to the flooding of the rice fields thousands of miles of borrow pits and ditches, as well as sloughs and innumerable rain water puddles serve as breeding sites for the mosquitoes which have over-wintered. Subsequent generations of these mosquitoes infest the many breeding sites created when the rice fields are flooded. In addition the initial flooding of the rice fields frequently produces a "single" brood of "flood-water" mosquitoes.

Favorable breeding sites result from seepage through the border levees of the rice fields, shallow and open areas in the paddies, the formation of algal mats, and thin stands of rice. In the fall when the rice paddies are drained prior to harvest large numbers of larvae and pupae, entrapped in the remaining puddles and shallow water, may emerge before the field is dry. When the fields are slow in draining and drying a number of generations may be produced (Freeborn 1917) at the time when the breeding of *Anopheles freeborni* is at its maximum.

The weeds on the levees and ditch banks as well as the rice itself provide excellent shelter for the mosquitoes from the strong winds and high summer temperatures. From fall until spring the over-wintering mosquitoes may be found in dense growths of weeds, under bridges, in buildings, and other places throughout the rice area which afford protection from the weather.

Control Problems.—Most of the breeding sites in the rice field areas are accessible only by foot or airplane; this restricts the use of power spray and aerosol equipment to areas adjacent to the roads. Repetitive larviciding of large areas by hand or airplane during a period of at least 4 months is not economically feasible, particularly in view of the small annual tax revenue of 5 to 15 cents an acre which the mosquito abatement districts accrue from the rice lands. The flooding of the rice fields in the spring and the draining in the fall each extend through a period of about 2 months. This makes the timing of control operations difficult and reduces their efficiency and effectiveness accordingly.

Species Involved.—In discussing the species of mosquitoes which are of importance in the rice fields of California it is impossible to lay down hard and fast

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[2] California Crop and Livestock Reporting Service.
[3] California State Department of Public Health. 1951. Mosquito Abatement in California, Bulletin. VC-1.
[4] California State Department of Public Health. 1953. California's Health. 11(7): 56.

rules. The period and intensity of breeding varies from year to year, between different areas of the state, and even from rice field to rice field. Observations made by many workers have shown that the breeding also varies from paddy to paddy and even within each paddy. Weather is the most obvious and influencing factor; when it is optimum for the rice it is likewise optimum for the mosquitoes. Periods of cool weather in the summer decrease the current breeding intensity and may retard the breeding during the rest of the season.[5]

Aedes dorsalis (Meig.), a "flood-water" mosquito, has been established in many of the rice fields of California. Since 1935 *Aedes nigromaculis* (Ludlow) has gradually been supplanting the fresh water strain of *Aedes dorsalis*.[3] The breeding habits and other characteristics of these two species are so similar that for practical control purposes they are considered the same mosquito. Therefore the two species will be considered as one, and when *A. dorsalis* is mentioned reference is also made to *A. nigromaculis*. When a pasture or other land infested with the eggs of this mosquito is prepared for rice and flooded, large numbers of larvae are produced, and the previously established infestation continues in the rice field. The initial flooding of a mosquito-egg-infested rice field produces a "single" brood of *A. dorsalis*. Mosquito control workers in California have found that the eggs of *A. dorsalis* overwinter in the soil, and that some of the eggs will remain viable in fallow fields for several years. Herms & Gray (1944) reported an account of the survival of *A. dorsalis* eggs in a dry marsh for about 10 years. For a number of years *A. dorsalis* has been a serious pest in the rice areas of California. These mosquitoes, originating in infested rice fields, may disseminate throughout the surrounding area as far as 5 miles, infesting other rice fields and suitable breeding sites, and plaguing the residents and cattle of the area.

When people in California speak of the rice field mosquitoes they are usually referring to *Anopheles freeborni* (Aitken). This mosquito readily enters residences and all types of buildings and shelters where it can be found from August until April. Whenever the weather is mild or a building is heated it becomes active and is an annoying pest. On warm days it leaves its shelter and feeds, particularly about the time of sunset. At 7:00 A.M. in mid-February, at a barren airport area more than 5 miles from the nearest rice field, it was feeding in such numbers that it drove the people indoors. During the fall in uncontrolled areas swarms of this mosquito may be seen following pedestrians down the street, and sometimes harvest crews in the rice fields will quit work when these mosquitoes become active in the late afternoon.

During the period of February through April the over-wintering *Anopheles freeborni* females leave their shelters, disperse and lay their eggs; from that time until July or August the subsequent generations of this mosquito are seldom seen. Borrow pits, puddles, ditches and sloughs which are warmed by the sun, protected from the wind, and contain emergent vegetation or algae favor oviposition. The larvae are first found widely scattered in small numbers; gradually they increase until by June considerable numbers may be found in some places. Rice fields with clean levees do not become infested until late June or July when the rice is about 15 inches high and affords conditions suitable for oviposition (Marcus 1950). Sperbeck (1950) and others have found that rice fields with weeds and rice growing on the leeves and into the margins of the paddies may become infested much earlier than those with clean levees. It has been found that the infestation and occurrence of *A. freeborni* varies greatly from rice field to rice field, paddy to paddy, and frequently during the breeding season. Herms & Gray (1944) found that the concentration of the mineral content and the stagnation of the water in rice fields located in a clay soil area produces a condition unsuitable for *A. freeborni*. Purdy (1925), Aitken (1945), and later workers have found that *A. freeborni* was not found in rice fields in which there was an abundance of the blue-green algae *Tolypothrix*.

Culex tarsalis according to Brookman (1950) is the most widespread and abundant *Culex* species in California. Although this mosquito over winters in the adult stage, all stages may be found throughout the year except during the coldest

[5] Hall, L. L., 1953. Unpublished data. Butte County Mosquito Abatement District.

weather.[6] As early as June and as late as October it may occur in such numbers as to constitute a pest. During February and March the overwintering females become active and lay their eggs in the same breeding sites as *Anopheles freeborni*, as well as those which are devoid of vegetation and more subject to the weather. In 1950 in the Sacramento Valley one mosquito abatement district found it necessary to start larviciding operations in the middle of February for the control of *C. tarsalis*. The larvae are found in the rice fields before those of *A. freeborni* and usually in greater numbers until late July or August. The breeding increases from June until it reaches a peak in late July and in August, then declines until by the time the rice is drained it is of minor importance. Since 1952 the breeding intensity of *C. tarsalis* in the rice fields has become greater and of longer duration. If this becomes the breeding pattern of *C. tarsalis* it will rival if not displace *A. freeborni* as the most prevalent mosquito in the rice field areas. During July and August, and recently in September, the *C. tarsalis* continually disseminate from the rice fields into the surrounding areas for at least 5 miles. In 1952 during the encephalitis epidemic mosquito control workers in the San Joaquin Valley observed large numbers of *C. tarsalis* in communities as far as 7 miles distant from their breeding sites. During periods of fluctuating temperature the dissemination becomes definite mass movements of large numbers of mosquitoes. By the first of November the breeding has so decreased that very few larvae are found, and the mosquitoes are seldom seen except in shelters. Periods of unusually mild weather during the winter stimulate breeding temporarily.

METHODS.—The standard larviciding methods will control the *Aedes dorsalis* larvae in the recently flooded rice fields but these methods are not satisfactory from an economic and operational standpoint for use by mosquito abatement districts. This is especially true when large acreages of infested rice fields must be treated in a short period of time in order to protect the adjacent populated areas (Portman & Williams 1952). Sperbeck (1948) devised a method of controlling the *A. dorsalis* larvae which consisted of submerging a 1-gallon can of 25 per cent DDT emulsible concentrate in the water inlet of each rice paddy after the larvae had appeared. Two small holes in the top of the can permitted small quantities of the concentrate to gradually diffuse into the water. Although this method gave excellent results, except in a few small areas into which the circulating water did not reach, it is not practical from an operational standpoint. The dosage is uncontrolled and the large acreage involved requires thousands of cans to be set and their operation inspected within a period of a few days.

A method of applying wettable powder DDT with the seed rice when it is plane-sown in the recently flooded rice fields was first proposed by Sperbeck (1949). With Herms (1952) he developed this procedure which provides the only practical method known today. Fifty per cent DDT wettable powder is distributed and mixed with the damp seed rice as it is dumped from the sacks into the plane-loading hopper. It is added to the seed rice in such a quantity as to give a dosage rate of 0.25 to 0.5 pound of DDT per acre. The powder adheres to the hulls of the seeds until they rest on the submerged soil of the flooded paddy where it mixes with the water and is slightly dispersed. Maximum control is not obtained in fields which have been flooded for such a length of time that late, fourth-instar larvae and pupae are present before the fields are treated, as these stages are not affected by the wettable powder DDT.

Portman & Williams (1952) found that the spraying of dry rice fields prior to flooding with a DDT spray at a rate of 1 pound of DDT per acre resulted in 100 per cent control of the *Aedes dorsalis* larvae. They also found that the application of 50 per cent DDT wettable powder with the seed rice, at the rate of 2 pounds per acre, also controlled the tadpole shrimps, *Apus oryzaphagus* n. sp. and *Apus biggsi* n. sp., and the larvae of the giant scavenger water beetle, *Hydrous triangularis* (Say), which have been rice pests of considerable importance in California. The resultant wide-spread use of wettable powder DDT by rice growers for the control of these rice pests has in turn not only assisted the mosquito abatement districts in the control of *A. dorsalis* but

[6] California State Department of Public Health. 1953. California's Health. 10(17): 136.

has also provided control of this mosquito in many of the rice areas of the state outside of the districts. The adult stages of *A. dorsalis* and *A. nigromaculis* are effectively controlled by aerosols.

In the rice field areas of California the control of *Culex tarsalis* is not in most instances differentiated from that of *Anopheles freeborni*. The methods applicable to *C. tarsalis* are also applicable to *A. freeborni*, which is in all stages more susceptible than *C. tarsalis* to the toxicants now in use. The formulations and dosage rates are usually designed to be effective for both species because of the frequency with which they occur together, both in the adult stage and as larvae. Therefore the control of both species is considered at the same time. The control methods and formulations used by the various mosquito abatement districts vary from district to district. Each district employs the methods and formulations which provide satisfactory control within its financial and operational limitations.

Two methods are used in the control of the overwintering *Anopheles freeborni* and *Culex tarsalis*. In the late fall and early spring all places of shelter in the suburban and rural rice areas, where the overwintering mosquitoes have accumulated, are treated with aerosol. The aerosol is generated by means of a vehicle-exhaust, thermal aerosol generator such as designed by Raley (1947), a similar device developed locally, or a large, commercial aerosol generator. Oil based, 5 to 10 per cent DDT formulations are generally used. In areas where DDT is no longer effective on *C. tarsalis* the districts use lindane, BHC or other toxicants in varying amounts in an oil base. Other districts incorporate 2 per cent by volume of a thiocyanate,[7] which causes the mosquitoes to leave the recesses of the shelter, thus assuring a more complete knockdown and kill. Although the aerosol is only effective on the mosquitoes present at the time of treatment it does provide considerable relief to the people whose buildings are treated. The dense white clouds and the wisps of aerosol seeping out of the shelters creates a very favorable psychological impression.

The other method of controlling the over-wintering mosquitoes makes use of the DDT residual spray which has worldwide acceptance in anopheline mosquito control programs (Bradley & Saylor 1949). Oil based or water emulsion sprays containing 0.2 to 0.4 pound of DDT per gallon are applied at the rate of 1 to 2 gallons per 1,000 square feet. Only those portions of the barns, chicken coops, culverts, under houses and other places of shelter where mosquitoes accumulate are sprayed. Observations and comments by property owners during the past 4 years indicate that the spray deposit is effective throughout the winter. In some places it has been found that the deposit is visible and effective for a year or longer. Mosquito collection records of the past 4 years show that during the winter *Anopheles freeborni* and *Culex tarsalis* move from shelter to shelter.[8] The residual spray has been found to be not only more effective over a longer period of time than the use of aerosol but also provides some control during the following breeding season.

Larviciding by hand or power sprayers begins in the spring when the first larvae appear. In some years this may be as early as mid-February or as late as the first part of April, depending upon the weather. The control of the early breeding in borrow pits, ditches, sloughs, rain-water puddles and other sites throughout an extensive area is accepted practice. It delays and initially decreases the infestation of the rice fields as well as reducing the pest problem in the area. Due to the cost of repetitive plane and ground larviciding operations, complete control of the breeding occurring in the rice fields and adjacent areas during the summer is not attempted. Throughout the season the accessible breeding sites, particularly those near communities are regularly inspected and controlled by ground spray equipment. In some instances heavy infestations occurring along the borders of rice fields are also controlled.

The *Culex tarsalis* during the first part of the summer and later both the *C. tarsalis* and *Anopheles freeborni* which invade the populated areas are controlled by aerosols. An aerosol formulation which has been used successfully for 5 years contains 10 per cent DDT in a diesel oil base, with 2 per cent thiocyanates.[7] A petroleum by-product[9] which has a higher DDT

[7] Rohm and Haas, *Lethane 384*.
[8] Unpublished records. Bureau of Vector Control, California State Department of Public Health, and The Butte County Mosquito Abatement District.
[9] Standard Oil Company of California, Base Oil Wt.

solubility factor and higher volatility temperature than diesel oil is also incorporated in the formulation to produce a heavier and more dense aerosol. In areas where *C. tarsalis* exhibits a resistance to DDT, lindane, BHC and other toxicants are used. Aerosol operations, which are dependent upon the prevailing atmospheric conditions, are not successful when the air is moving faster than 2 miles per hour, the temperature is too high or too low, and when there are inversions or rising air currents. Aerosol operations for area control are carried out after sunset and before sunrise; for premise control work other times of the day may be satisfactory. The efficiency of the operations depends upon the length of time the aerosol persists, its concentration, and its penetration into the innumerable places where the mosquitoes are resting. Because optimum conditions for aerosol operations occur sporadically it is necessary to consider this method as a means of supplementary control.

The adult stages of all four species are effectively controlled in rural areas by means of plane spraying, which can be done between sunrise and sunset, when satisfactory atmospheric conditions for aerosols do not prevail. A spray formulation, consisting of a dieldrin water emulsion containing 0.024 pound of dieldrin per gallon and 2 per cent thiocyanates[7] by volume, when applied at the rate of 4 gallons per acre resulted in nearly 100 per cent control. This formulation when applied at the same rate to breeding places has given 100 per cent control of the first- through early fourth-instar larvae of *Aedes dorsalis* and *A. nigromaculis*. Most of the mosquitoes produced by the few surviving late fourth-instar larvae and pupae died within a day after emerging. The over-all control was better than 99 per cent. This formulation applied at the rate of 4 gallons per acre is not effective on the larvae and pupae of *Culex tarsalis*.[5]

Magy (1949) found that the application of 0.025 pound of DDT per acre gave a 98 per cent mortality of the *Anopheles freeborni* larvae in California rice fields. The oil based DDT larvicide was applied by an airplane equipped with a thermal, exhaust aerosol generator. He also found that the anopheline larvae recurred in the rice fields within 3 days after treatment. Sperbeck (1949) found that the larvae recurred within 4 days after using the same airplane spray equipment as Magy, and a similar DDT formulation applied at a somewhat higher rate. Sperbeck (1950) observed from one to six mosquitoes per lineal foot, hidden in the cool, shaded, protected areas at the base of weeds and rice near the edge of the water after the larvae had been controlled by plane spraying. He attributed the larvae which appeared within a few days after the plane spraying to the surviving gravid mosquitoes. In an effort to devise a formulation which was not only effective on the larvae but also the mosquitoes a number of tests were conducted. Oil-based and emulsion sprays containing various percentages of DDT, TDE, DDT-TDE combinations, and DDT supplemented by thiocyanates[7] and pyrethrum were tried. In all cases larvae recurred within a few days. A formulation containing 8.33 per cent DDT, 2 per cent pyrethrum, and 2 per cent thiocyanates[7] was applied at the rate of 1 quart per acre, but the larvae recurred and numerous mosquitoes survived.

In 1950 the author found that when the rice fields were plane-sprayed within 10 days prior to draining, a minimum of mosquitoes were produced by the recurring infestation. The airplane aerosol generating equipment and pilot were the same as employed by Magy and Sperbeck. A spray was formulated containing 0.8 pound of DDT per gallon, 2 per cent thiocyanates,[7] 0.5 per cent spreading agent,[10] 71.5 per cent diesel oil and 20 per cent of a petroleum by-product[9] by volume. The petroleum by-product produced a heavier "aerosol-spray" and a stronger film on the water than diesel oil. This formulation when applied at an average rate of 0.19 gallon per acre to 18,000 acres resulted in a larval mortality of 94 to 98 per cent and very few surviving mosquitoes. The pest problem resulting from the mosquitoes produced by the recurring infestation was minimal.

In the following 4 years 155,000 acres of rice fields were plane-sprayed within approximately 10 days of the time that most of the fields were drained. The insecticide was applied at an average rate of 0.27 gallon per acre by means of a spray boom instead of a thermal, exhaust

[10] Rohm and Haas, *Triton B-1956*.

aerosol generator. This permitted the spraying operations to be carried out when it was too windy for satisfactory aerosol application. A very high mosquito and anopheline larval mortality was obtained. During the operations of the first year the thiocyanates were increased to 4 per cent to obtain a higher mortality of the *Culex tarsalis* larvae. This revised formulation was used the following 2 years, but the thiocyanates were increased 8 per cent during the last year to again increase the mortality of the *C. tarsalis* larvae. During the 4 years the infestation of the rice fields by *C. tarsalis* has not only increased but the intensity of breeding has continued instead of declining during September. In the last 3 years of these fall plane-spraying operations only small numbers of mosquitoes were found in the sprayed rice fields at harvest time, and the few that invaded the populated areas and survived until spring were not a pest problem.

SUMMARY AND CONCLUSIONS.—*Aedes dorsalis* (Megi.), *Aedes nigromaculis* (Ludlow), *Anopheles freeborni* (Aitken) and *Culex tarsalis* (Coq.) are the principal species of mosquitoes infesting the rice fields of California. *A. dorsalis* is being supplanted by *A. nigromaculis*; and *A. freeborni* the most prevalent species may with a few years be rivaled or supplanted by *C. tarsalis*. *A. freeborni* and *C. tarsalis* are not only serious pests but vectors of malaria and encephalitis, respectively.

The control of the over-wintering mosquitoes *Anopheles freeborni* and *Culex tarsalis* is by means of applying aerosol or DDT residual spray to their places of shelter, the latter being more effective. Controlling the larvae of these species in the late winter and spring delays and reduces the initial infestation of the rice fields.

Aedes dorsalis and *A. nigromaculis* larvae can be effectively and economically controlled by the application of 0.5 pound of 50 per cent DDT wettable powder with the seed rice. The adult stages can be effectively controlled by aerosols.

Mosquitoes invading nearby urban and suburban areas can be controlled by aerosols. This method must be considered only as a supplementary means of control because optimum aerosol conditions occur sporadically. Mosquitoes in rural areas can be controlled by the plane-spray application of dieldrin as a water emulsion at the rate of 0.1 pound per acre when and where aerosols cannot be used effectively.

The plane-spraying of the rice fields within 10 days prior to draining results in effective control of *Anopheles freeborni, Culex tarsalis* and *A. freeborni* larvae, and partial control of *C. tarsalis* larvae. The small numbers of surviving mosquitoes and those produced by recurring infestations of the rice fields and adjacent breeding sites after treatment have in nearly all instances not presented a pest problem during the last 3 years.

The control of the mosquitoes breeding in the rice field areas within mosquito abatement districts has greatly reduced the pest problem and health hazard which formerly existed. But there are still sufficient mosquito vectors present in those areas to maintain a potential hazard of malaria and encephalitis. These mosquito vectors with other favorable factors may result in the occurrence of these diseases in epidemic proportions as was the case in 1952. The increasing prevalence of *Culex tarsalis,* the vector of encephalitis, and its increasing resistance to insecticides presents a serious problem to those concerned with mosquito control and the health of the public.

Considerable information concerning the principal mosquitoes infesting the rice field areas and their control is available. But, there is a great need for more complete, specific information and operational research aimed at the development of methods and insecticides which will provide effective control within the budgetary limitations of the mosquito abatement districts.

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Evaluation of Interval and Dosage in Bollworm Control[1]

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Abundant rainfall in the Brazos Valley near College Station, Texas, during 1953 apparently influenced the development of the cotton bollworm, *Heliothis armigera* (Hbn.). Two injurious generations of this insect appeared over much of the cotton acreage during July and August. In many instances where this pest was not controlled, heavy losses in yield resulted. The experiments considered in this paper were directed primarily toward bollworm control in an effort to study the effects of different intervals between applications of insecticides and the effects of increased dosages when applied at intervals greater than 5 days. The boll weevil, *Anthonomus grandis* (Boh.), infestation was extremely light during 1953 and did not reach a damaging peak until the last week in August or first week in September. This was especially true of experiment 1. In experiment 2, weevils occurred in slightly heavier numbers. The principal insect damage in these tests was from the bollworm.

EXPERIMENTAL PROCEDURE.—Experiment 1 and experiment 2 were arranged in randomized blocks with each treatment and the check replicated four times. The plots in experiment 1 were 0.1 acre in size, 12 rows wide and 109 feet in length. The picking area was 0.05 acre in size. In experiment 2, the plots were 0.08 acre in size, 12 rows wide and 87 feet in length. The picking area was 0.04 acre in size.

The insecticides were applied with the 3-row power sprayer described by Gaines *et al.* (1952) at the rate of 7.5 gallons of spray per acre using a pressure of 60 pounds per square inch. The approximate speed of the sprayer was 5 miles per hour, and 3 nozzles per row were used to deliver the toxicants.

RESULTS.—The field cotton used in experiment 1, table 1, was very late-planted and had only started squaring vigorously about July 20. The experiment was designed to compare the effectiveness of DDT on control of the bollworm when applied at the rate of 0.75 pound active ingredient per acre at 5- and 7-day intervals and 1.5 pounds active ingredient per acre at 5-, 7- and 10-day intervals. BHC at the rate of 0.45 pound of the gamma isomer per acre was added to the last application

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