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BIONOMICS AND CONTROL OF *CULEX PIPIENS FATIGANS* WIED. IN CEYLON

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SYNOPSIS

The climatic and housing conditions which favour the breeding of *Culex pipiens fatigans* in Ceylon, and its life-cycle and resting-habits, are described. The results of the treatment of breeding-places (mainly catch-pits) and the interior of houses with various insecticides of specific action on larvae or adults, in different preparations and concentrations, are given, and suggestions are made for the control of the mosquito on this island. The fundamental measure for successful control is efficient sanitation, but until this can be achieved, application of larvicides seems to be the method of choice.

Culex pipiens fatigans Wied. (*C. quinquefasciatus* Say in American literature), the common house mosquito, is not only an important vector of filariasis but also a great nuisance wherever it occurs. It has very wide distribution, covering almost all the sub-tropical and tropical regions. In Ceylon this mosquito is the main, if not the only, vector of urban filariasis (*Wuchereria bancrofti*), its natural infection rates ranging from 2.2 to 21.0, with a mean rate of 8.8.[2] Filariasis has become the most important insect-borne disease in this island, as malaria is now well under control.[5]

Indoor residual spraying with DDT (occasionally with BHC) has been undertaken regularly as an antimâlaria measure over a large part of the island since 1947. However, many people in Kurunegala municipality now object to the spraying of their houses as they feel that DDT is no longer useful for mosquito control. This may adversely affect public support for malaria control programmes. Although the local malaria vector, *Anopheles culicifacies*, is still susceptible to DDT and BHC, the residual spraying with these insecticides seems to have failed in controlling *C. fatigans*.

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In order to discover the cause of the failure of DDT residual spraying in controlling *C. fatigans*, and possible effective and cheap control measures, studies were made of the bionomics of this mosquito (particularly its resting-habits in insecticide-treated and untreated houses) and of different insecticides tested in the laboratory and in the field.

Climatic, Field and Housing Conditions

Kurunegala, where the present studies on *C. fatigans* have been carried out, is the capital town of the North Western Province, and is situated about 60 miles (100 km) north-east of Colombo. The municipal limits of Kurunegala cover an area of 4.75 square miles (12.3 km^2). The town, which is about 380 feet (115 m) above main sea level, lies in a plain surrounded by hills of moderate elevation. Its population is about 17 000. Although it is a municipal unit of 2600 houses, typically village-like areas are found within the truly urban areas.

Kurunegala is within the intermediate zone of Ceylon, getting its rain from both the south-west and the north-east monsoon. The wettest months are April, May, October, and November. The meteorological data for the period from September 1952 to September 1954, when these studies were being undertaken, are given in Table I.

Housing conditions

Although there are a large number of big, modern, stone-built houses in the town, our study has been exclusively confined to the rural type of small, ill-ventilated house of which there are many. These houses conform to the following general pattern: in front is a small, open veranda 3-5 ft (1-1.5 m) wide extending the length of the frontage; the middle portion of the house is usually a bedroom 10 ft (3.04 m) square, and behind is the counterpart of the veranda, except that it is enclosed by a wall—namely, the kitchen and store portion. In some houses the middle portion may be divided so that one half-open sitting-room and a fully enclosed bedroom are formed. The bedroom is sometimes provided with a window 2 ft (0.6 m) square, or may have none. The walls, 7-8 ft (2.1-2.4 m) in height, are of wattle and daub (wooden framework packed with earth) and always plastered with earth; they are sometimes lime-washed. The roof, which is invariably thatched with cadjan (woven coconut leaves), is about 10-12 ft (3-3.5 m) at its highest part.

Occasionally an open cattle shed, 8 ft (2.4 m) square, where cattle are tethered at night, is found outside.

The bedroom is always full of furniture, which usually comprises a wooden bed with mattress, a small table, two or three chairs, boxes to store clothes and other valuables, and a rack to house all odds and ends which have to be kept secure. The walls are more or less covered, with clothes

TABLE I. METEOROLOGICAL DATA OF KURUNEGALA, CEYLON

Year & month	Mean temperature (°F)		Relative humidity (%)		Total rainfall (inches) *
	maximum	minimum	day	night	
1952					
September	89.7	74.4	72	86	2.41
October	85.5	73.5	76	90	13.98
November	86.2	71.0	72	93	12.26
December	87.0	71.0	68	90	3.61
1953					
January	87.1	69.4	70	90	0.86
February	90.0	69.2	63	87	3.58
March	91.9	73.0	71	90	5.18
April	91.2	74.0	74	90	7.41
May	93.1	77.8	65	82	0.14
June	91.2	77.1	67	82	1.38
July	85.0	73.8	77	86	16.78
August	87.8	75.6	70	82	1.46
September	87.4	74.6	70	84	4.90
October	86.7	73.4	74	88	18.59
November	87.2	70.6	66	90	5.02
December	85.9	70.4	65	87	1.87
1954					
January	86.1	71.4	72	88	1.48
February	89.5	69.6	64	95	2.69
March	90.6	71.5	66	95	14.73
April	90.0	74.8	74	93	11.46
May	89.3	76.4	76	88	7.35
June	87.3	76.1	71	86	3.63
July	86.4	75.0	72	88	4.60
August	85.8	74.9	76	88	5.43
September	87.8	74.8	67	88	1.65

* 1 inch = 25.4 mm

hanging from rails, framed pictures, calendars, etc. Very occasionally the bed may be provided with a mosquito-net.

Breeding-places of C. fatigans

The chief breeding-place of *C. fatigans* in the town is the catch-pit. This is a cement-built pit $1\frac{1}{2} \times 1\frac{1}{2} \times 2$ ft ($0.45 \times 0.45 \times 0.6$ m) or $2 \times 2 \times 2$ ft ($0.6 \times 0.6 \times 0.6$ m), constructed behind the dry-earth latrine (bucket system); it collects urine and water and, occasionally, small quantities of faeces which also get in by misuse. The water content of the catch-pit is therefore highly polluted and ideal for the breeding of *C. fatigans*. Breeding is very heavy and 50-100 larvae per dipper (4.5 inches (10.4 cm) diameter) is the usual density. Other breeding-places include cesspools, septic tanks, coconut-husk pits, coconut trenches, discarded receptacles, road gullies, and drains.

The coconut-husk pit is not an important breeding-site here, but is a big problem in those areas where large numbers of pits are found, for example, semi-urban areas along the south-west coast of Ceylon. These husk pits are of various dimensions, from 6×10 ft (2.4×3.0 m) upwards, and are usually 2-3 ft (0.6-0.9 m) deep; in them coconut husks are soaked in water for several months and undergo decomposition, after which the coconut fibres can be separated. The water becomes highly polluted and mosquitos breed profusely in it.

Life-cycle, Number of Eggs, and Emergence Ratio

As it was not possible to vary the conditions of temperature, the observations on the duration of the various stages in the life-cycle of the mosquito were made in the laboratory only at a room temperature of 80.6°-82.6°F (27°-28°C) then prevailing in Ceylon. The egg-rafts laid by hundreds of *C. fatigans* which had been caught in the wild were kept separately in well-water. When the larvae hatched, a small quantity of dry prawn powder was added daily as food. Table II shows the frequency distribution of the

TABLE II. FREQUENCY DISTRIBUTION OF MINIMUM DURATION OF VARIOUS STAGES OF 92 EGG-RAFTS

Stage	Number of days	Number of rafts
Egg	1	49
	2	43
Larva	4	7
	5	6
	6	37
	7	26
	8	12
	9	4
Pupa	1	23
	2	57
	3	11
	4	1

minimum duration of the various stages of the life-cycle developing from the 92 rafts.

The duration of the period between egg and adult averaged 9.7 days; the egg-stage was 1-2 days (average 1.35 days); the larval stage, 4-9 days (average 6.45 days); and the pupal stage, 1-4 days (average 1.9 days).

Experiments with egg-rafts kept in water obtained from catch-pits instead of in well-water were also made, and more or less the same results were found.

The duration of development from egg to adult observed in Calcutta [16] was 8-10 days during January (54°F minimum and 81°F maximum (12.2°-27.2°C)). Pomeroy [13] reported, without mentioning the temperature, that the minimum duration of the egg-stage was 24 hours, of the larval stage, 120 hours, and of the pupal stage, 48 hours.

The frequency distribution of number of eggs per raft among the 91 unfragmented egg-rafts laid in the laboratory was as follows:

Number of eggs	*Number of rafts*
Under 54	3
55-74	11
75-94	24
95-114	23
115-134	13
135-154	6
155-174	3
175-194	4
195-214	2
Over 250	2

The number of eggs per raft laid by *C. fatigans* in the laboratory was mostly within the range of 75-114. Of the 50 rafts with a total of 6370 eggs laid and kept in our laboratory, 3643 eggs were pupated and 3091 (1496 males and 1595 females) emerged. The emergence and sex ratio of *C. fatigans* were studied intensively by Qutubuddin. [14]

Oviposition in Relation to Insecticide-treated Waters

On the selection of oviposition sites for *C. fatigans*, de Zulueta [21] reported that this mosquito prefers a high organic content of water and is guided mainly by chemical and scent stimuli of water contents. It completely avoids the sodium chloride solution for oviposition. Manefield [9] also mentioned that, when allowed a choice, this mosquito showed complete preference for the foul water, no eggs whatever being laid in tap-water.

In our experiments, whitish enamelled trays ($7.5 \times 9.5 \times 2$ inches — about $19 \times 24 \times 5$ cm) were left on the ground of a room (temperature 27°-28°C) which had been mosquito-proofed. About a hundred wild-caught *C. fatigans*, mostly fed, were released in the room every night. For each test two trays were set up in the centre of the room, one foot (0.3 m) apart from each other. One contained tap-water for control purposes; the other contained the same quantity of tap-water, but an insecticide had been added. DDT water-dispersible powder (75%), hexachlorocyclohexane (BHC)—Gammexane P. 520—, dieldrin granules (1% and 5%), dieldrin dust (2%), and dieldrin water-dispersible powder (25%) were used at the dosage of 0.1 lb per acre (0.113 kg per hectare (ha)) of actual toxicant. Catch-pit water was also tested in comparison with tap-water. The lights were turned off, and in the morning the number of egg-rafts was counted.

From the few experiments carried out it was seen that *C. fatigans* definitely prefers catch-pit water to tap-water for oviposition. The addition of insecticide seems to increase the attractiveness of the tap-water.

Experiments were also carried out to compare different insecticides; they showed that dieldrin seems to be a little more attractive to mosquitos than DDT and BHC. These experiments were repeated under more or less natural conditions by placing the trays close together on a table in an open room so that wild mosquitos could come in at night for oviposition. Tap-water was replaced by water collected from catch-pits. In addition to the above insecticides, aldrin dust (2½%) and aldrin water-dispersible powder (25%) were also tested at the same dosage—that is, 0.1 lb per acre (0.113 kg per ha). The trays were left unchanged in content and position for three weeks, but the egg-rafts were removed every morning after they had been counted. The results are shown in Table III.

Table III shows that insecticide-treated catch-pit water did not repel *C. fatigans* from oviposition, even on the night of treatment. During the first week after treatment of the water, comparatively fewer egg-rafts were laid in insecticide-treated waters, particularly those treated with BHC. Generally speaking, more egg-rafts were laid on waters treated with dieldrin or aldrin than on those treated with DDT or BHC.

Several tests were made to see whether these chemicals had any larvicidal residual effect; one egg-raft was placed in each of the trays containing catch-pit water treated with the above insecticides at the same dosages, and in the check tray containing catch-pit water only. These trays were left at ordinary room temperature (27°-28°C), with the contents unchanged, for daily observation up to two weeks after treatment. Dry prawn powder was added to each tray every morning to feed the larvae hatched out from the egg-rafts.

Larvae hatched out in all the trays and were very active during their first stage. In the check tray and the DDT trays they developed normally up to adult stage; in aldrin and BHC a few succeeded in developing into adults but they took longer; while in dieldrin all died during the first or second stages. Many of the adults died after their emergence in the insecticide-treated waters, but not a single one did so in the check tray.

TABLE III. NUMBER OF EGG-RAFTS LAID BY C. FATIGANS IN INSECTICIDE-TREATED CATCH-PIT WATERS

Number of days after treatment	Check	DDT (75% water dispersible)	Gamma-BHC (6.5%)	Dieldrin				Aldrin	
				1% granules	5% granules	2% dust	25% water dispersible	2½% dust	25% water dispersible
1	8	5	0	5	6	1	1	3	4
2	2	0	0	0	1	3	1	2	2
3	4	3	1	5	1	3	4	3	3
4	0	2	0	0	0	1	1	2	5
5	1	0	0	0	0	0	0	0	0
6	1	0	1	1	0	1	0	0	0
7	1	0	1	2	0	4	0	1	4
1st week total	17	10	3	13	8	13	7	11	18
8	4	1	6	4	3	0	4	2	14
9	5	2	7	2	6	3	1	4	11
10	7	3	9	13	20	0	9	1	11
11	3	0	4	1	11	1	4	2	2
12	2	2	0	2	5	0	2	1	2
13	4	1	4	4	7	0	3	3	2
14	10	2	5	5	19	11	5	7	9
2nd week total	35	11	35	31	71	15	28	20	51
15	19	9	4	6	11	5	9	6	10
16	3	2	0	2	5	3	0	1	4
17	4	2	1	0	6	2	1	2	3
18	3	0	0	0	4	2	1	1	2
19	1	0	0	1	3	0	0	3	2
20	0	1	0	5	0	0	1	0	0
21	0	0	3	0	1	1	0	1	1
3rd week total	30	14	8	14	30	13	12	14	22
Grand total	82	35	46	58	109	41	47	45	91

All the insecticide-treated waters lost their effectiveness after a week, except that treated with dieldrin, in which only a few larvae developed normally.

Larval Breeding Habitats

C. fatigans can breed in almost any kind of water collection with a very wide range of pH value, although it prefers polluted water. Woodhill [19] reported that *C. fatigans* was able to grow in water of pH 4.2-9.0, and Senior-White [17] even found its larvae and pupae growing in a tank of dilute HCl with a pH value of about 1.6.

The breeding-places of *C. fatigans* may be summarized as follows, according to the order of preference:

(1) Artificial water-containers: catch-pits, cesspools, septic tanks, coconut-husk pits, coconut trenches, discarded receptacles, road gullies, borrow-pits, etc.

(2) Natural water-containers: ground pools, drains, rice-fields, marshes, etc.

(3) Plant containers: tops of coconut palms, fallen coconut shells, tree holes, bamboo stumps, etc.

A general survey of all available water collections was made in the Kurunegala municipality and its vicinity some time after heavy rains, in October-December 1953 and May 1954. The results are shown in Table IV.

TABLE IV. BREEDING-PLACES OF C. FATIGANS

Type of breeding-place	Number examined	Positive	
		number	%
Catch-pits	347	180	51.9
Coconut-husk pits	18	14	77.7
Coconut trenches	472	40	8.5
Borrow-pits	105	23	21.9
Soakage pits	17	9	52.9
Quarry pits	52	0	0
Wells	59	0	0
Earth drains	44	0	0
Pools	254	23	9
Swamps	27	1	3.7
Rice-fields and irrigation channels	57	2	3.5
Streams	4	0	0
Tree holes	444	6	(negligible)
Bamboo stumps	3763	1	(negligible)

Of the above water collections available for mosquito-breeding, catch-pits, coconut-husk pits, coconut trenches, borrow-pits, soakage pits, and pools are the most important for *C. fatigans*. Discarded tins and receptacles, fallen coconut shells, built drains and tanks, road gullies and lime pits, when present, are also important.

As mentioned above, *C. fatigans* can breed in almost any water collection, though preferring highly polluted water. The hydrogen-ion concentration of the environment is of little importance as a factor in development. In water of high salinity—for example, 10 g NaCl added to a litre of water as reported by Woodhill,[20]—the larvae could not normally develop. A few samples of water collected from places where *C. fatigans* were present, as well as from those which were always negative for such larvae, were chemically analysed. The results are given in Table V. The data on chemical analysis of water from the flourishing *C. fatigans* breeding-places reported by Senior-White [17] are also included for ready reference.

TABLE V. CHEMICAL ANALYSIS OF WATER SAMPLES COLLECTED FROM BREEDING- AND NON-BREEDING-PLACES OF C. FATIGANS

Characteristics of water	Breeding-places				Non-breeding-places		
	catch-pits	husk pit	borrow-pit	those reported by Senior-White [17]	paddy-field	quarry pit	pool
Free ammonia (p.p.m.)	>1	—	0.24	25.75	0.04	>1	—
Alb. ammonia (p.p.m.)	>1	—	>1	25.5	0.70	>1	—
Chlorides (p.p.m.)	120-620	600	8	220	7	70	580
Total solids (p.p.m.)	378-2677	1624	150	—	71	285	1349
Total alkalinity (p.p.m.)	250-1600	575	60	820	40	40	300
Total hardness (p.p.m.)	260-850	930	60	—	40	90	780
Nitrites	0	0	0	0.0025	0	0	0
Nitrates	0	0	0	0.6	0	0	0
Electrical conductivity (1/megohm-cm^3)	725-5500	2250	130	—	80	400	1800
pH value	7.1-8.4	7.1	7.0	7.5	7.0	6.8	7.5
Oxygen absorbed from $KMnO_4$ in 4 hours at room temperature (30°C)	33.6-58.4	28.6	3.7	370.0 *	2.7	7.2	6.65

* Oxygen consumed at 212°F (100°C) at 30 minutes

It seems that there was not much difference in the water contents of *C. fatigans* breeding- and non-breeding-places. However, the most favourable breeding-places, such as catch-pits and coconut-husk pits, showed much higher figures of oxygen consumed; this means that these waters were highly polluted and thus more attractive for oviposition by *C. fatigans*.

Adult Resting-Habits in Insecticide-sprayed and Unsprayed Areas

The resting-habits of mosquitos are of great importance in relation to the effectiveness of insecticide residual-spraying. During routine collections for the assessment of control results, we found over 60% of *C. fatigans* resting on furniture, clothes, mosquito nets, hangings, etc., which are not sprayed as an antimalaria measure; moreover, the inhabitants do not like to have these objects sprayed. In order to find out whether the resting-habits of mosquitos were changed by residual spraying, observations were made on their normal behaviour in unsprayed areas.

Five houses each in five sections of the Kurunegala municipality were selected as catching-stations, and total catches were made weekly in each house. Altogether, 110 collections were made during the period from November 1952 to February 1953 when regular spraying as an antimalaria measure was undertaken with 75% DDT water-dispersible powder at the dosage of 60 mg per square foot (646 mg per square metre) at intervals of about three months.

Observations in unsprayed areas were made in April-May 1954 for a very short period (10 days), owing to the financial difficulty of travelling to southern Ceylon, where most of the places have never been sprayed with any residual insecticide (for example, Kalutara) or where treatment has been undertaken with larvicides only for *C. fatigans* control (for example, Matara).

As shown in Table VI, about 70% of female *C. fatigans* rested on hangings, clothes and furniture, which were not sprayed during routine application of insecticides for malaria control. At Kurunegala alone, about 55% were found on unsprayed surfaces in the sprayed houses.

The resting-habits of *C. fatigans* were similar in both insecticide-sprayed and unsprayed areas. Clothes, hangings and mosquito-nets were the places most favoured for resting by *C. fatigans* in daytime, over 50% of the mosquitos being found there. A considerable number of *C. fatigans* rested behind and underneath the furniture and beds. More mosquitos were found on the lower middle part of walls than on the upper middle part. Lime-washed mud walls were much less favoured by mosquitos than cadjan walls. Relatively far fewer mosquitos were found under the roofs in the houses of Kalutara and Matara than in Kurunegala, but this was largely

TABLE VI. RESTING-HABITS OF C. FATIGANS (AVERAGE PER CATCH PER HOUSE)

Type of houses	Locality	Wall-height (m) 0-1		1-2		2 and over		Underneath roof		Hangings and clothes		Furniture	
		F	M	F	M	F	M	F	M	F	M	F	M
Cadjan roof & lime-washed mud wall	Kurunegala	1	0.5	1	0.5	1	0.5	10	4	13	6	3	1
	Matara	6	3	2	1	2	1	2	2	29	24	6	5
	Kalutara	0	0	2	1	0	0	0	0	2	0	2	0
Cadjan roof & cadjan wall	Matara	4	2	8	7	11	7	1	0.5	70	66	7	7
	Kalutara	1	0.2	8	1	0	0	3	2	11	2	0.2	0
Average of females (%)		6		10		7		8		60		9	

because we were not able to search most parts of the roofs in the two former places, as they were fairly high.

However, Deane [7] reported from Brazil that only about 30% of female *C. fatigans* rest behind and under furniture and on clothes, 20% on the upper portions of walls (3 m above the ground), and the remainder on the lower portions of walls. Rachou & Lima,[15] also in Brazil, found about 60% of female *C. fatigans* resting on the ceilings and upper parts of walls, and the rest on the lower walls, curtains, and furniture.

Deane [7] mentioned that about 50% of *C. fatigans* were found in bedrooms and the remainder in other rooms in the following decreasing order: living-rooms, kitchens, hallways, and toilets. Of 187 houses searched at Kurunegala during the period of May-July 1954, we found about 80% of *C. fatigans* (709 females and 406 males) in bedrooms, 16% (136 females and 95 males) in kitchens, and 4% (43 females and 22 males) in other places such as sitting-rooms and verandas. No mosquitos were caught in lavatories.

Daytime and Night-time Catches of Adult Mosquitos

In order to see whether there was any hourly difference between the number of mosquitos resting in dwelling-houses during the daytime and that entering houses at night, collections were made as follows:

Daytime catches

Five houses were selected in a village within the municipal area, and total collections of mosquitos were carried out daily at different hours (at 7 a.m., 9 a.m., and 11 a.m., and at 2 p.m. and 4 p.m.), for different houses by rotation. Altogether 55 daily catches for each house were made, and the results are given in Table VII.

TABLE VII. TOTAL NUMBER OF 55 DAILY CATCHES OF C. FATIGANS IN HOUSES (NOVEMBER 1952-FEBRUARY 1953)

House	7 a.m.	9 a.m.	11 a.m.	2 p.m.	4 p.m.
A	734	683	657	570	567
B	327	311	310	245	301
C	438	402	460	513	388
D	261	280	316	253	281
E	427	456	291	455	378
Total	2187	2132	2034	2036	1915
Average per catch	39.6	38.8	37	37	34.8

The number of *C. fatigans* present in houses during the daytime appears to decrease gradually as time goes on, but the difference was very small. Once the mosquitos settled down in houses after sunrise they would remain there if not disturbed.

Night-time catches

Over a period of one year, fortnightly collections were made of mosquitos entering and resting in the same houses; the insects were caught by tube. Fifteen minutes were spent at the beginning of each hour, starting from 6 p.m. and continuing throughout the night until 5 a.m., so that six collections were done before midnight and six after.

As shown in Table VIII, the number of mosquitos caught in most of the months was too small to draw any conclusion; it seems that there was not much difference in the number of mosquitos entering a house at different hours of the night.

Control of Adult Mosquitos

DDT

The Kurunegala municipality and its vicinity were highly malarious and had therefore been sprayed more or less regularly with DDT, and very occasionally with BHC, in the antimalaria campaign from August 1946 up to the end of 1953. Different preparations of DDT were used: at first kerosene solution, then xylene emulsion, and lastly water suspension.

TABLE VIII. NIGHT-TIME CATCHES OF FEMALE C. FATIGANS (NOVEMBER 1952-OCTOBER 1953)

Month	Before midnight						After midnight					
	6-7	7-8	8-9	9-10	10-11	11-12	0-1	1-2	2-3	3-4	4-5	5-6
November	37	19	24	23	25	18	15	23	13	10	16	13
December	17	7	7	9	14	11	10	9	6	2	16	6
January	7	5	6	7	12	6	8	4	5	6	4	8
February	9	16	19	11	18	12	13	16	6	10	7	4
March	10	12	16	21	30	42	41	28	28	27	14	16
April	3	4	6	3	3	3	4	2	3	2	3	3
May	0	0	0	1	1	0	0	0	0	0	0	0
June	1	2	1	3	2	2	3	1	0	1	1	3
July	4	8	6	5	5	6	7	6	4	8	9	3
August	0	4	2	1	1	3	4	2	2	0	4	4
September	0	0	0	0	1	0	0	1	0	1	0	2
October	2	4	2	2	1	2	1	1	3	2	0	3
Average per catch for whole year	7.5	6.7	7.4	7.1	9.4	8.7	8.8	7.7	5.8	5.7	6.1	5.6

The dosage of DDT was decreased from 100 mg to 60 mg per sq. ft (1.076 g to 646 mg per m²), and the spraying interval was increased from 6 to 12 weeks.

As the whole municipality and its vicinity were under routine spraying, no suitable places near our laboratory could be taken as check stations. However, judging from the high density of *C. fatigans* mosquitos throughout the whole spraying cycle, it would seem that DDT residual spraying as an antimalaria measure had actually little effect on the control of *C. fatigans*. The following tabulation shows findings made during one spraying cycle (mid-December 1952 to end of February 1953) on the weekly density of female mosquitos caught in five DDT-sprayed (60 mg per sq. ft—646 mg per m²) houses in each of three villages within the municipal area; the figures indicate average per catch per house.

One week before present treatment or 11th week after previous treatment	*Weeks after treatment*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
12	13	10	11	11	21	19	22	13	27	27

Even in the first week after spraying there was no reduction at all in mosquito density. The same results were also obtained in night catches in the house—that is, more mosquitos entered and rested in the house after the DDT spraying. The total number of female *C. fatigans* by hourly catches from 6 p.m. throughout the night till 5 a.m. are as follows:

Night before spraying	393
Same night, after spraying	426
One week after spraying	406

In order to see whether the failure of DDT in the control of *C. fatigans* was due to the development of DDT resistance after continuous spraying for the past six years or to the peculiar resting-habits of the mosquito, reference was made to the experiment carried out by the Division of Medical Entomology in 1947 at Nugegoda (near Colombo) where no insecticide had been used before.

The results of the Nugegoda experiment were reported in 1948 by the Director of Medical and Sanitary Services in Ceylon.[3] In the houses sprayed with a DDT suspension of 27 mg per sq. ft (291 mg per m^2) there was no reduction in culicine mosquito (mainly *C. fatigans*) density even during the first week after spraying, although in those sprayed with DDT kerosene solution (60 mg per sq. ft—646 mg per m^2) and emulsion (118 mg per sq. ft—1.27 g per m^2) better results were obtained.

" The percentages of mosquitos surviving for 24 hours after removal from the sprayed houses were surprisingly high and were, in fact, practically the same as those obtained from mosquitos caught in the unsprayed houses. Many of these were resting on furniture and hangings which had not been sprayed, and according to the high survival rates obtained showed that the mosquitos had not remained sufficiently long on the sprayed surfaces to become poisoned." [3]

BHC

Observations were made of mosquito density in the houses of one village within the municipal area, which in September 1953 had been sprayed with BHC (Gammexane P.520, containing 6.5% gamma-BHC) at the dosage of about 11 mg gamma-BHC per square foot (118 mg per m^2), as an emergency measure for malaria control.

Weekly total catches in 10 houses revealed that mosquito density decreased slightly for six weeks after spraying. However, the same extent of reduction in mosquitos also occurred during the same period in another village which had been sprayed with DDT half a year before. No conclusion can therefore be reached from this observation.

Dieldrin

Two villages (one sprayed with DDT two months previously and the other five months previously) were sprayed by us with 25% dieldrin water-dispersible powder at the dosages of 25 mg and 50 mg per sq. ft (269 mg and 538 mg per m^2) respectively. There was considerable reduction, but not to a satisfactory level, of mosquito density after spraying. Again, no conclusion could be drawn, because the checking stations also showed a certain decrease in mosquitos during the same period.

The ratio of the mosquitos recovered from the houses sprayed with DDT or BHC was about 50: 50 on the sprayed and unsprayed surfaces. Most of the mosquitos collected even from the sprayed surfaces could live longer than 48 hours, while in houses sprayed with dieldrin the majority were found on unsprayed surfaces such as clothes and hangings. DDT definitely failed to control *C. fatigans* mosquitos. Further studies are required to assess the value of BHC and dieldrin, but preliminary observations show that they also gave no satisfactory results when applied as an antimalaria measure, that is, when they were sprayed on walls and roofs only.

As the control of *C. fatigans* by adulticides was not satisfactory, various larvicides were tested.

Control of Larvae

For the control of *C. fatigans,* the chief vector of urban filariasis, the Ceylon Filariasis Campaign has been using only larvicides. The two formulations used were: (1) BHC in oil (1 ounce Gammexane larvicide dust containing 3% gamma-BHC in 1 gallon of heavy diesel oil (6.2 g per litre)) and (2) Gammexane larvicide applied as a dust.

Results were satisfactory at first, but recently the products used (a 10% gamma-BHC larvicide in place of the original 3% gamma-BHC) have proved far less successful. We therefore carried out investigations to find, first, a more effective larvicidal preparation, and second, an easier and cheaper method of application than spraying with knapsack equipment.

Laboratory tests

Twenty *C. fatigans* larvae of the fourth stage collected from the field were put in each enamel tray (for dimensions, see page 613) of approximately 0.5 sq. ft (0.046 m^2) in surface area, and 1.4 litres of well-water were added. The experiment was carried out at room temperature (27°-28°C).

Different dosages of (1) DDT (75% water-dispersible powder of the Michigan Chemical Corporation), (2) BHC (Gammexane P.520 of Imperial Chemical Industries, containing 6.5% gamma-BHC), (3) dieldrin (2% dust, 1% granules, 5% granules, and 25% water-dispersible powder of Shell Co.), and (4) aldrin (2½% dust and 25% water-dispersible powder of Shell Co.) were tested. Two to five replicas were made for each dosage of each kind of the insecticides.

The number of dead larvae was counted 3, 6, 12 and 24 hours after application. The larvae which pupated during the test were not taken into consideration in calculating the results. The data are given in Table IX.

TABLE IX. LABORATORY TESTS ON INSECTICIDES TO 4th-STAGE LARVAE OF C. FATIGANS AT ROOM TEMPERATURE (27°-28°C) (AVERAGE OF 2-5 REPLICAS)

Insecticides	Quantity used (mg)	Dosage active ingredient (lb per acre*)	% mortality after	
			12 hours	24 hours
DDT: 75% water-dispersible powder	0.33	0.05	18	28
BHC: P.520 water-dispersible powder	4.0	,,	64	89
Dieldrin: 2% dust	12.5	,,	55	80
1% granules	25.0	,,	60	76
5% granules	5.0	,,	63	82
25% water-dispersible powder	1.0	,,	34	50
Aldrin: 2½% dust	10.0	,,	36	47
25% water-dispersible powder	1.0	,,	32	40
DDT: 75% water-dispersible powder	0.66	0.1	8	28
BHC: P.520 water-dispersible powder	8.0	,,	61	90
Dieldrin: 2% dust	25.0	,,	79	96
1% granules	50.0	,,	80	92
5% granules	10.0	,,	80	92
25% water-dispersible powder	2.0	,,	40	75
Aldrin: 2½% dust	20.0	,,	35	53
25% water-dispersible powder	2.0	,,	13	25
DDT: 75% water-dispersible powder	1.33	0.2	12	40
BHC: P.520 water-dispersible powder	16.0	,,	83	95
Dieldrin: 2% dust	50.0	,,	73	95
1% granules	100.0	,,	80	93
5% granules	20.0	,,	89	93
25% water-dispersible powder	4.0	,,	73	85
Aldrin: 2½% dust	40.0	,,	38	67
25% water-dispersible powder	4.0	,,	23	43
Control (check tray)	—	—	0	0

* 0.1 lb per acre = 0.113 kg per ha.

Tests of these insecticides showed that DDT water-dispersible powder was the least effective for controlling *C. fatigans* larvae. BHC water-dispersible powder and dieldrin dusts and granules gave the best results, with 100% kill of the larvae in 24 hours, as observed in some of our tests.

The water-dispersible powders of dieldrin and aldrin were not so effective as their preparations in the form of dusts and granules.

As to the dosages tested, it seems that there was not much significant difference in effectiveness between 0.1 and 0.2 lb per acre (0.113 and 0.226 kg per ha).

Field tests

Catch-pits are the most important breeding-places of *C. fatigans* in Ceylon, and were therefore selected for our field tests. The insecticides and dosages employed were the same as in the laboratory tests. A dosage of 1 lb per acre (0.113 kg per ha) was also tried in order to see whether any residual larvicidal effect could be obtained.

The larval (all stages) density was measured by dipper (approximately 4.5 in. (10 cm) in diameter and 2 in. (5 cm) deep) before and after treatment. In the majority of the catch-pits examined for the experiment, the larval density was about 50-100 per dipper. Daily examinations were made up to two weeks after application of the insecticides. Any heavy rain, or the removal of the catch-pit contents during the period of tests, was also noted.

The effectiveness of the different kinds of insecticide tested in the field was more or less similar to the results obtained in the laboratory. BHC water-dispersible powder and dieldrin dusts and granules have the best results, while DDT water-dispersible powder had almost no effect, and aldrin was poor.

At the dosage of 0.1-1 lb per acre (0.113-1.13 kg per ha), BHC and dieldrin gave about 95%, and a few 100%, kills of the larvae on the fourth day after application. It therefore seemed necessary to apply the larvicide once a week, even at the highest dosage.

Municipality-wide control experiments

As malaria was under control in the Kurunegala municipality and its vicinity, insecticide residual spraying was suspended in this area from the beginning of 1954. Satisfactory results had been obtained with larvicides for *C. fatigans* control in small-scale field tests in December 1953; experiments on municipality-wide control of larvae were therefore carried out in June-September 1954.

A systematic and thorough survey of all the *C. fatigans* breeding-places was made and mapped out. The area was divided into several sections, one being used as a check station and the others receiving treatment with different chemicals. After treatment the breeding-places, mainly catch-pits, were checked weekly. If positive (that is, if large larvae, or pupae, or both were present), they were re-treated; otherwise, they were left without further treatment until they became positive again. Larval density was counted by dipper. At the same time a weekly collection of adult mosquitos was made in the catching stations (10 houses each) in different sections.

Technical DDT, BHC, and dieldrin were dissolved in light diesel oil and tested at 1-4 lb per acre (about 1.13 kg-4.5 kg per ha). The optimum dosage of gamma-BHC and dieldrin was found to be 3-4 lb per acre (3.4 kg-4.5 kg per ha), which killed all the larvae within 1-2 days after application. The same dosage of DDT did not give very satisfactory results.

The chemicals locally available were therefore tested in different formulations and dosages as follows:

(1) *BHC dust and oil solution* : Gammexane larvicide containing 10% gamma-BHC, diluted with local soapstone to 1%, and 2% gamma-BHC, applied by duster. The oil solution was prepared by dissolving 1, 2, and 4 ounces of the 10% gamma-BHC larvicide in one gallon of diesel oil (6.2 g, 12.4 g, and 25 g per litre), applied by Flit-gun.

(2) *BHC and dieldrin bricks* made of local and imported plaster of Paris. These were soaked with water-dispersible BHC or dieldrin powder. To 1125 g of plaster of Paris were added 170 g of Gammexane P.520 (containing 6.5% gamma-BHC) and 750 ml of water. Each brick was cut into 10 small blocks ($2 \times 2 \times 2$ in.—$5.08 \times 5.08 \times 5.08$ cm) and each block thus contained 1.1 g of gamma-BHC or about 1% gamma-BHC. One block was put into each catch-pit. For the dieldrin bricks, 125 g of 25% water-dispersible dieldrin was used, each block containing 3.1 g of technical dieldrin.

(3) *Dieldrin granules* : 1% and 5%, sprinkled by hand.

(4) *Dieldrin 2% dust* : applied by duster.

(5) *Dieldrin sawdust* : this was prepared by soaking 450 g of sawdust with 2 and 4 fluid ounces (114 cm^3) of Dieldrex 15 (containing approximately 19% dieldrin) and each diluted with 40 fluid ounces (1140 cm^3) of water. In another preparation, 20 fluid ounces (568 cm^3) of light diesel oil were used instead of water.

(6) *Shell Malariol* : sprayed by Flit-gun

(7) *Shell Malariol HS (containing 5% DDT)*: 10 fluid ounces to one gallon (about 62.5 cm^3 to one litre) of light diesel oil

(8) *Shell Malariol emulsion (containing 25% DDT)* : 2 and 4 fluid ounces to one gallon of water (about 12.5 cm^3 and 25 cm^3 to one litre)

(9) *Dieldrex 15* : 8 fluid ounces to one gallon (about 50 cm^3 per litre) of light diesel oil; and 4 and 8 fluid ounces to one gallon (about 25 cm^3 and 50 cm^3 per litre) of water

(10) *Light diesel oil*

As shown in Table X, only dieldrin water emulsion (Dieldrex 15 in water) and BHC oil solution (Gammexane larvicide in diesel oil) gave satisfactory results, at the dosages of 2-3 lb per acre (about 2.25 kg to 3.4 kg per ha) of active ingredient. In over 94% of the trials, all the larvae were killed within a week after treatment. Only a small percentage of the formulations had residual effect and remained free of the larvae and pupae for 2-3 weeks.

Dieldrin and BHC bricks made of local plaster of Paris were almost entirely unsatisfactory. The whole piece dissolved within a couple of days and gave almost no kill of the larvae. Some of those made of imported plaster of Paris, however, had a lasting effect up to 12 weeks. In some of the catch-pits treated with dieldrin sawdust (25 g of the preparation to a catch-pit, the dosage of active ingredient thus being about 10 lb per acre —about 11.3 kg per ha), there was also lasting effect for 8 weeks owing to the gradual dissolution of the sawdust. As a whole, these preparations of bricks and sawdust did not give effective control, as many of the catch-pits treated had large larvae and pupae a week after application.

It is difficult to explain why dieldrin granules entirely failed in these municipality-wide control experiments, even when applied at such a high dosage as 20 lb per acre (about 23 kg per ha), while in the laboratory, and in small-scale field tests carried out half a year earlier, these showed very satisfactory results at the dosages of only 0.1-1 lb per acre (about 0.113-1.13 kg per ha). Laboratory tests were therefore repeated with dieldrin granules of the same stock at the dosage of 1 lb per acre (about 1.13 kg per ha). The results were the same as those obtained previously, that is, 95%-100% of the larvae killed in 24 hours.

It is interesting to note that Gammexane larvicide applied as dust at the dosages of 5-10 lb per acre (about 5.65-11.3 kg per ha) gave very poor results, while when it was applied in diesel oil solution at a much lower dosage (2 lb per acre—about 2.2 kg per ha) it worked satisfactorily. Diesel oil alone, however, as shown in Table XII, was not effective.

Discussion and Conclusions

In Ceylon *C. fatigans* breeds principally in catch-pits; if their contents could be removed thoroughly and regularly once a week (the egg and larval stages together last about 8 days) it would certainly eliminate the main breeding-place of this mosquito. In practice, however, this proved to be impossible. A small quantity of the contents was always left over in the bottom of the catch-pit and many, if not most, of the larvae, after being disturbed, sank to the bottom to continue their development. Better equipment, such as a pump with a long hose attached to a tank lorry, might be used to achieve thorough cleaning of the pit. In certain urban and municipal areas, covers were used for catch-pits, but they were unsatisfactory as they did not fit tightly.

TABLE X. EXPERIMENTS ON MUNICIPALITY-WIDE CONTROL OF C. FATIGANS IN CATCH-PITS (SURFACE-AREA ABOUT 2.2 SQUARE FEET (0.223 m^2) WITH LARVICIDES: JUNE-SEPTEMBER 1954

Chemicals	Formulation *	Quantity used per catch-pit	Approximate dosage of active ingredient (lb per acre **)	Number of trials	One week after treatment	
					% positive †	% negative ††
Light diesel oil	—	0.5 fl. oz.	—	10	90	10
Shell Malariol	—	0.5 fl. oz.	—	40	90	10
Shell Malariol HS (5% DDT)	10 fl. oz. to 1 gallon diesel oil	0.5 fl. oz.	2	55	92	8
Shell Malariol emulsion (DDT 25%)	2 fl. oz. to 1 gallon water	0.6 fl. oz.	2	34	85	15
	4 fl. oz. to 1 gallon water	0.6 fl. oz.	4	10	90	10
Gammexane Larvicide dust (10% γ-BHC)	1 1b to 9 lb soapstone	13 g	5	167	67	33
	2 lb to 9 lb soapstone	13 g	10	39	41	59
Gammexane Larvicide oil solution (10% γ-BHC)	1 fl. oz. to 1 gallon diesel oil	0.5 fl. oz.	0.4	17	50	50
	2 fl. oz. to 1 gallon diesel oil	0.5 fl. oz.	1.0	48	13	87
	4 fl. oz. to 1 gallon diesel oil	0.5 fl. oz.	2.0	17	6	94
Gammexane P. 520 (6.5% γ-BHC)	Brick of local plaster of Paris	17 g	—	7	70	30
	Brick of imported plaster of Paris	17 g	—	7	70	30
Dieldrin 1%	Granules	2.5 g	1	38	90	10
		5.0 g	2	126	80	20
		10.0 g	4	44	77	23
Dieldrin 5%	Granules	5.0 g	10	40	65	35
		10.0 g	20	48	48	52
Dieldrin 2%	Dust	10.0 g	8	66	42	58
		20.0 g	16	35	37	63
Dieldrin 25% water-dispersible powder	Bricks of local plaster of Paris	12.5 g	—	8	100	0
	Bricks of imported plaster of Paris	12.5 g	—	10	20	80
Dieldrex 15 solution and emulsion	8 fl. oz. to 1 gallon oil	0.5 fl. oz.	6	18	60	40
	4 fl. oz. to 1 gallon water	0.6 fl. oz.	3	63	0	100

* 1 fluid ounce (fl. oz.) per gallon = about 6.25 cm^3 per litre.
** 1 lb. per acre = about 1.13 kg per ha.
† Large larvae (3rd and 4th stages) and/or pupae were present.
†† No large larvae and pupae were present.

DDT residual spraying definitely failed to control the *C. fatigans* mosquito. Even on the night of spraying or during the first week afterwards no reduction of mosquito density was observed. The failure of DDT adulticide in *C. fatigans* control has also been reported by many other workers, such as Wharton [18] in Malaya, Brown & Williams [1] in the island of St. Croix, Davidson [6] in East Africa, and Charles [4] in British Guiana. Wharton [18] mentioned that DDT had a marked irritant effect, driving the mosquito out and so reducing the biting rate. In our observations we noticed no such effect, even on the night of spraying or on the following morning after 60 mg of DDT per square foot had been applied.

No conclusive data were obtained from BHC and dieldrin experiments on adult control. However, judging from the resting-habits of *C. fatigans*, which prefers to rest on hangings and clothes, and behind and underneath furniture, adulticides would not seem to be satisfactory for effective control —at least when they are applied by the usual methods of antimalaria campaigns (that is, only the walls and roofs are sprayed). As shown in both insecticide-treated and untreated houses (as well as from the reported experiment at Nugegoda where DDT was sprayed for the first time), over 50% of *C. fatigans* were found on hangings, clothes, and furniture. These are generally not allowed to be sprayed, particularly if water-dispersible powder is used, as the spraying leaves whitish spots. The failure of adulticides in *C. fatigans* control because of the peculiar resting-habits of the mosquito was also observed by Charles,[4] who stated that " none of the insecticides used in the experiment were capable, by residual application alone, of producing complete control of *C. fatigans*, presumably because of the eclectic habits of the mosquito ". Moreover, even if adulticides were satisfactory they are generally not so economic as larvicides when applied to urban and municipal areas.

As adulticides appear to provide an unsatisfactory solution for *C. fatigans* control, larvicides seem to be the choice. It is much more difficult to control culicine larvae than anopheline larvae because the breeding-places of the former usually contain a high proportion of organic matter and scum which interferes with the action of insecticides. A much greater dosage is therefore required. Hurlbut & Bohart [8] discussed the factors affecting the larvicidal action of DDT on *C. fatigans* and pointed out that the larvae in foul water were much more difficult to kill than those in distilled water.

Of the different larvicides and formulations tested, dieldrin and BHC in oil solution or water emulsion were the best. The optimum dosage is 3-4 lb per acre (about 3.4-4.5 kg per ha), which killed all the larvae within a week after treatment. It is, however, necessary to apply the formulation weekly. About 0.5-0.6 fluid ounces (about 14-17 cm^3) of dieldrin water emulsion (4 fluid ounces of Dieldrex 15 to one gallon of water (about 25 cm^3 to one litre), or its equivalent prepared with technical dieldrin in diesel oil or emulsifier), or BHC oil solution, were sufficient to spray a catch-pit (approximately 2.2 sq. ft (about 0.2 m^2) in surface area). The cost was approximately half a cent of Ceylon currency.[a] For the application, a Flit-gun hand sprayer of the continuous-spray type can be employed. In certain urban and municipal areas, such as Colombo, the contents of catch-pits are removed weekly. Since the removal is not thorough, it is better to instruct the same labourers to apply the larvicide to the bottom of the catch-pits after cleaning. This should increase the efficiency of the larvicide and at the same time decrease the costs of material and labour.

As to the formulations of water emulsion and oil solution, the former seems to be more suitable and effective for application to the generally highly polluted breeding-places of *C. fatigans*. Owing to the scum and other organic matter on the water surface, an oil solution does not spread well and usually forms many globules, thereby giving very poor results, as experienced by many field workers in Ceylon. A good spreading agent must therefore be added. The dosage rate based on pound per acre customarily used seems to be of little value for catch-pits and other *C. fatigans* breeding-places because of their depth and the intensity of breeding. The parts-per-million (p.p.m.) or volume basis is more reliable, as suggested by Parthasarathy & Kruse [12] who also recommended a dosage of 0.5 p.p.m. for grossly polluted pools. The dosage of 1 lb per acre (about 1.13 kg per ha) applied to the catch-pit in our experiments is equivalent to 0.4 p.p.m., and the optimum dosage of 3-4 lb per acre (3.4 kg-4.5 kg per ha) is equivalent to between 1.2 and 1.6 p.p.m.

As observed in both the laboratory and the field, the insecticide-treated waters did not repel oviposition by the mosquito, and some insecticides appeared to make the breeding-places even more attractive; many egg-rafts were laid on the night of treatment. Also, there was no larvicidal residual effect in catch-pit water even when the insecticides were applied at high dosages (3-4 lb per acre—3.4 kg-4.5 kg per ha). This was probably due to certain factors such as high concentration of organic matter, exposure to sunlight, partial removal of the contents, overflow during heavy rains, and heavy infestation of larvae. Pal & Sharma [11] mentioned that several workers have explained the lack of larvicidal residual effect in culicine breeding-places as being due to the fact that " insecticides are sorbed into bottom-mud complex of the pond and are not available to the larvae ". These factors would either cause deterioration of the insecticides or decrease the concentration. Although Mathis & Quarterman [10] reported that dieldrin at 1 lb per acre (about 1.13 kg per ha) controlled culicine breeding for over a year, we could not get good residual effect in highly polluted waters, probably because of the factors just mentioned. Only some of the dieldrin bricks and sawdust, which dissolved gradually in the water, gave lasting effect for 8-12 weeks.

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[a] 100 cents equals 1 rupee; 4.76 rupees equals 1 US dollar.

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RÉSUMÉ

Des essais de lutte contre *Culex pipiens fatigans*, vecteur de la filariose très répandu à Ceylan, ont été entrepris au moyen d'insecticides à effet rémanent. Ce moustique trouve facilement des gîtes favorables dans les fosses d'aisance et les cuves de rouissage des noix de coco, car il préfère l'eau polluée à l'eau pure. Le nombre de moustiques se reposant durant la journée à l'intérieur des habitations ou y pénétrant pendant la nuit est à peu près le même à différentes heures. Dans les habitations, qu'elles soient traitées ou non, le moustique se repose sur le mobilier, les vêtements ou le linge suspendus dans les pièces, c'est-à-dire dans les endroits où les pulvérisations ne peuvent guère les atteindre.

Les substances imagicides sont sans action notable sur ce moustique, surtout si elles sont appliquées selon les méthodes recommandées pour la lutte antipaludique (pulvérisations sur les parois et les plafonds).

Pour lutter efficacement, il faudrait drainer le sol, créer des égouts et vidanger régulièrement les fosses. En attendant l'exécution de ces mesures, la lutte antilarvaire s'impose de préférence à toute autre. La concentration des larvicides doit être plus élevée dans les eaux polluées, chargées de matières organiques absorbantes et parfois écumeuses, que dans les eaux claires. La dieldrine et le HCH en émulsion aqueuse ou en solution huileuse, à raison de 3,5-4,5 kg/ha, en pulvérisations hebdomadaires, semblent être les plus efficaces des larvicides que l'on peut se procurer facilement sur place.

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