BEHAVIORAL RESPONSES OF *ANOPHELES DARLINGI* IN SURINAME TO DDT RESIDUES ON HOUSE WALLS

J. A. ROZENDAAL,[1] J. P. M. VAN HOOF,[2] J. VOORHAM[2] AND B. F. J. OOSTBURG[3]

ABSTRACT. A study was conducted in Suriname on the effects of DDT residual house spray on the main vector of malaria, *Anopheles darlingi*. Results obtained with an experimental hut sprayed with DDT wettable powder (2 g/m^2 AI) were compared with results obtained with an unsprayed control hut. In the sprayed hut, entry rates were reduced by 32% and feeding success by 43.6%. The 24-h mortality of mosquitoes which entered the sprayed hut was 95% (range 85–100%) over the 10-month study period. After furnishing the sprayed hut according to local custom, no reduction in mortality was observed despite an abundance of unsprayed resting surfaces. Bioassays showed that the DDT deposits remained effective for at least 14 months. With excito-repellency test boxes an irritant effect caused by DDT on recently fed *An. darlingi* females was shown. With a choice-box experiment no preference for unsprayed over sprayed resting places could be demonstrated.

INTRODUCTION

Since 1958 there has been an attempt to reduce malaria first by HCH and from 1960 onwards by DDT residual spraying of houses in the interior of Suriname, so far without any obvious success. This lack of success might be attributed to low coverage which varied between 15 to 60% of available houses per spraying cycle. Barnes and Jenkins (1972) analyzed the sociological aspects of poor cooperation by the local population, the bush negroes. In addition to sociological factors another explanation could be entomological. Rozendaal (1989) studied the indoor resting period of *Anopheles darlingi* Root and found no day-resting; the mosquitoes remained indoors only for a number of hours at night. According to Bruce-Chwatt (1971), an indoor resting period of at least 12–18 h duration is needed to prevent malaria transmission with DDT residual house spraying. With shorter periods, like those observed for *An. darlingi* in Suriname, DDT house spraying could be expected to reduce but not interrupt transmission of malaria. However, success of DDT residual spraying will depend on a combination of factors such as DDT susceptibility, surface material, duration of vector-insecticide contact, degree of avoidance/repellency, indoor or outdoor biting, etc.

Resistance of *An. darlingi* to insecticides has not been reported from Suriname or any other South American country. In the Upper-Marowijne River area, Suriname, *An. darlingi* was found to be fully susceptible to DDT (Germanetto 1982, in an internal report of the Institut Pasteur, Cayenne, French Guyana). In the same area Hudson (1984) showed a reduction in the expected biting rate of *An. darlingi* by 20% after spraying a house with 2 g DDT/m^2.

It is obvious that a vector control program should be supported by more accurate entomological data. In this study data have been collected with experimental huts on mortality, feeding success, rate of entry and repellency in relation to DDT house spraying. Additional behavioral information was obtained with excito-repellency tests and with experiments in a choice-box for avoidance of DDT.

MATERIALS AND METHODS

Study area and population: In the most malarious area of Suriname, the Upper-Marowijne River and its tributaries, the Lawa and Tapanahony rivers, inhabited by the Djuka bush negro tribe, an experimental station called Abetredjoeka was selected out of 7 sampling stations (Fig. 1) (Rozendaal 1987). Abetredjoeka is a small bush negro settlement on one of the many islands in the river. Low population densities of *An. darlingi* occurred throughout the year.

Operation of experimental huts: Two experimental huts built with local materials and in the local style as described more extensively by Rozendaal (1989) were constructed in Abetredjoeka. One of the two huts was intended as a test hut which was to be sprayed with DDT and the other as a permanent unsprayed control hut. Mosquitoes were attracted by a man seated inside the hut between 1830 h and 0630 h. He did not collect the mosquitoes biting on his bare legs, but counted the total number biting per hour using a flashlight with a red filter to prevent disturbance. This method is sufficiently accurate because of the very low number of biting mosquitoes which makes recognition of individual mosquitoes easy. The huts were dimly illuminated with oil lamps which are also used indoors at night by the inhabitants. The entry

[1] Medical Mission, Paramaribo, Suriname. Present address: Division of Vector Biology and Control, World Health Organization, 1211 Geneva 27, Switzerland.

[2] Subfaculty of Biology, State University, Leiden, The Netherlands.

[3] Bureau of Public Health, Paramaribo, Suriname.

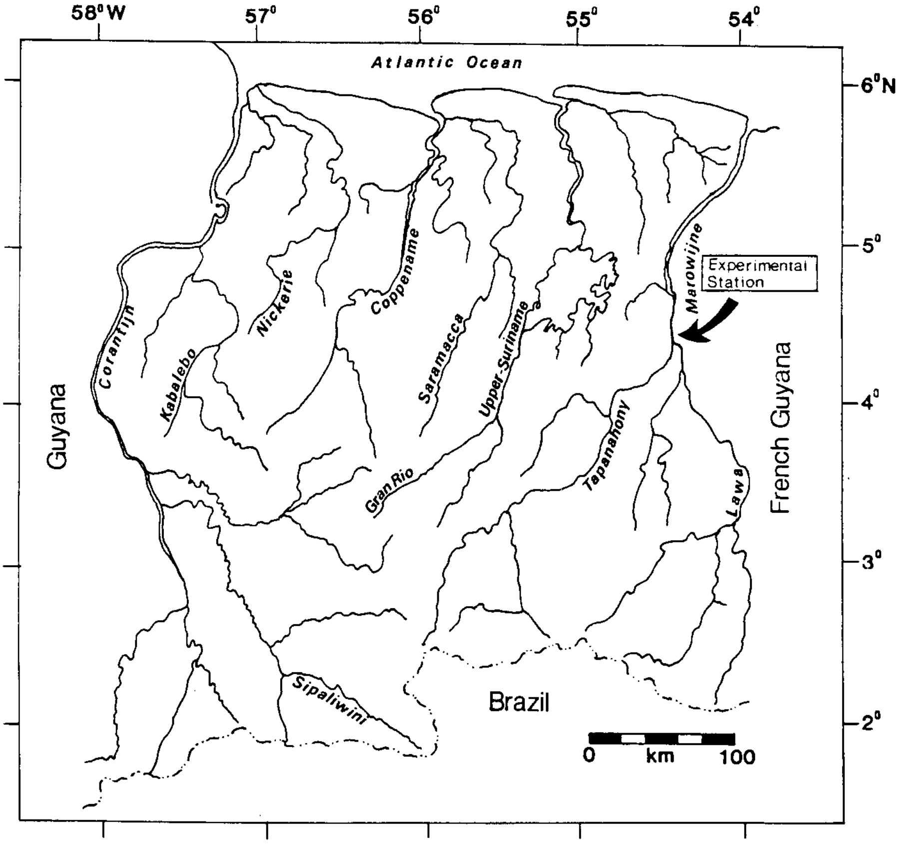

Fig. 1. Map of Suriname. The location of the experimental station Abetredjoeka is indicated by an arrow.

time and the time of biting were considered to be similar, since the pre-bite resting period had been shown to be very short, Charlwood (1980) and Hudson (1984), respectively, having reported 10 and 7.7 min for this period. Entry of mosquitoes was possible through the eave openings and especially made slits in the walls which were fitted with baffles to prevent uncontrolled escape. Two exit traps per hut served to collect exiting mosquitoes and were emptied at hourly intervals between 1830 h and 0730 h. Mosquitoes from the exit traps were transferred to plastic cups, covered with gauze, provided with cotton wool saturated in a sugar solution and held for 24 h to assess delayed mortality. At about 1000 h, dead mosquitoes were collected from sheets, which covered the floors of the huts. Of all mosquitoes collected, species and the Sella's stages (World Health Organization (WHO) 1975) were determined. Population mortality was calculated by adding the number collected dead from the floor to the number which died within 24 h from the exit traps, and dividing by the total collected from the floor and exit traps. Abbott's formula was used to calculate corrected mortality of anophelines for the control hut.

Before spraying with DDT, both huts were operated simultaneously for about four months to detect possible differences in attraction to *An. darlingi.* Subsequently the test hut was sprayed (June 11, 1985) with DDT wettable powder at 2 g/m^2 AI by an experienced sprayman. As has been practiced in the Suriname spraying program, the interior walls and the outer part of the walls close to the eave openings and the underside of the overhanging roof were sprayed.

Four months after the test hut was sprayed the operation of both huts was modified. Hourly observations of biting mosquitoes were discontinued. A person sleeping in a hammock without a mosquito net acted as a human bait. Although it can be expected that attraction to mosquitoes is similar, the results were analyzed for differences between the two methods.

Impact of furnishing a sprayed experimental hut: Surprisingly high mortality rates were observed in the DDT-sprayed house regardless of the short indoor resting period of *An. darlingi.* However, the small traditional houses of the bush negroes are cluttered with a large quantity and variety of objects: cooking utensils, washing equipment, clothes, bags, beds, hammocks and, unrolled at night, mosquito nets. Such objects are removed or covered during the spraying of a house and provide safe resting places for indoor biting and resting mosquitoes after the spraying. Consequently, we considered that under local circumstances the mortality rates might be lower because of the availability of safe resting places. To study this problem, the two experimental huts were furnished in the local way. Data about representative furniture were obtained by selecting eight houses at random and measuring and counting all objects and unsprayed surfaces in the interior.

Study methods were about the same as in the previous study, but the person sleeping in a hammock was only present between 2030 h and 0630 h, and exit traps were emptied at 0730 h. Since the many objects made it hard to detect dead mosquitoes, the hut was searched independently by two different persons.

The test hut for this study was not sprayed with DDT wettable powder but with DDT emulsion concentrate at 2 g/m^2 AI to study the residual effectiveness of this formulation which is routinely used for house spraying in Suriname because it is better accepted by the bush negroes. The test hut was sprayed on May 15, 1986.

Bioassay tests: Standardized bioassay tests were performed at regular intervals of about one month to determine the residual efficacy of DDT wettable powder and DDT emulsion concentrate (WHO 1975). Ten to 15 locally collected blood-fed *An. darlingi* females per cone were exposed for 30 min to randomly selected spots at different heights (40–215 cm) on the wooden walls and thatched roof. After the first test the same spots were used again in subsequent tests. After exposure the surviving mosquitoes were transferred to holding cups covered with gauze and provided with a piece of cotton wool soaked in sugar water. The cups were stored in a dark and relatively cool place, and the mortality was determined after 24 h.

Excito-repellency tests: Anopheles darlingi females entering bush negro houses in Suriname may easily avoid contact with DDT by selecting unsprayed resting places or by escaping from the house. Although the experimental hut study provides information on this subject, understanding of those data will be improved by use of the excito-repellency test boxes as described by the WHO (1975). In Brazil, Charlwood and Paraluppi (1978) and Roberts et al. (1984) used excito-repellency boxes designed by Rachou et al. (1973) to test the effect of DDT sprayed housewalls on the endophagic behavior of *An. darlingi.* Our box model combined the designs of Rachou et al. (1973) and the WHO (Fig. 2); dimensions were 50 × 50 × 50 cm, in one side

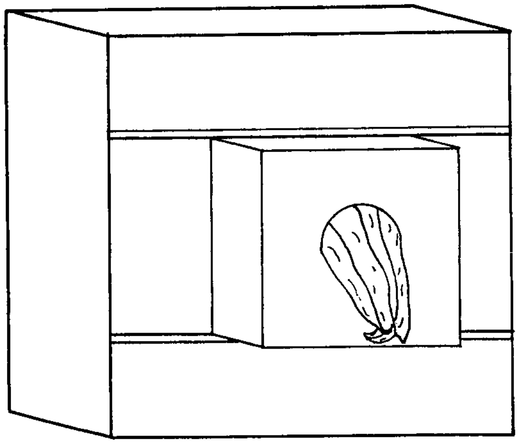

Fig. 2. Excito-repellency box (dimensions: 50 × 50 × 50 cm) with removable exit trap at the front. Mosquitoes can be collected via the cotton sleeve.

an opening of 20 × 20 cm to which an exit trap of 25 × 25 × 25 cm was fitted. The control box was lined with unsprayed absorbent poster paper, and the test box with similar paper sprayed with DDT wettable powder at approximately 2 g/m^2 AI.

Whereas Roberts et al. (1984) tested the behavior of physiologically different *An. darlingi* populations, we only used recently fed mosquitoes which were just caught on human baits. The tests were conducted around midnight to imitate as much as possible the natural conditions. The mosquitoes were released in the box through the funnel of the exit trap. The funnel opening was closed for 5 min during which the mosquitoes could adapt themselves to the environment. After opening the funnel, mosquitoes were collected from the exit trap in intervals of 10 min during a total test period of 1 h. Shorter periods were thought to cause too much disturbance. Only about 20–30 specimens were used per test to facilitate emptying of the exit traps. The boxes were placed inside a house with the very dim illumination of an oil lamp. A flashlight was used to facilitate collection of the mosquitoes from the exit trap with an aspirator. The box was opened at the end of the test period by carefully lifting the removable lid. All living and dead mosquitoes still in the box were collected and counted.

Choice box test for avoidance of DDT: The question arose whether a mosquito irritated after contact with DDT would be able to distinguish between sprayed and unsprayed surfaces. This was studied using the test boxes as described above, but with the possibility of dividing the interior into two equal-sized compartments by a sliding wall and without the exit trap opening. One compartment was lined with

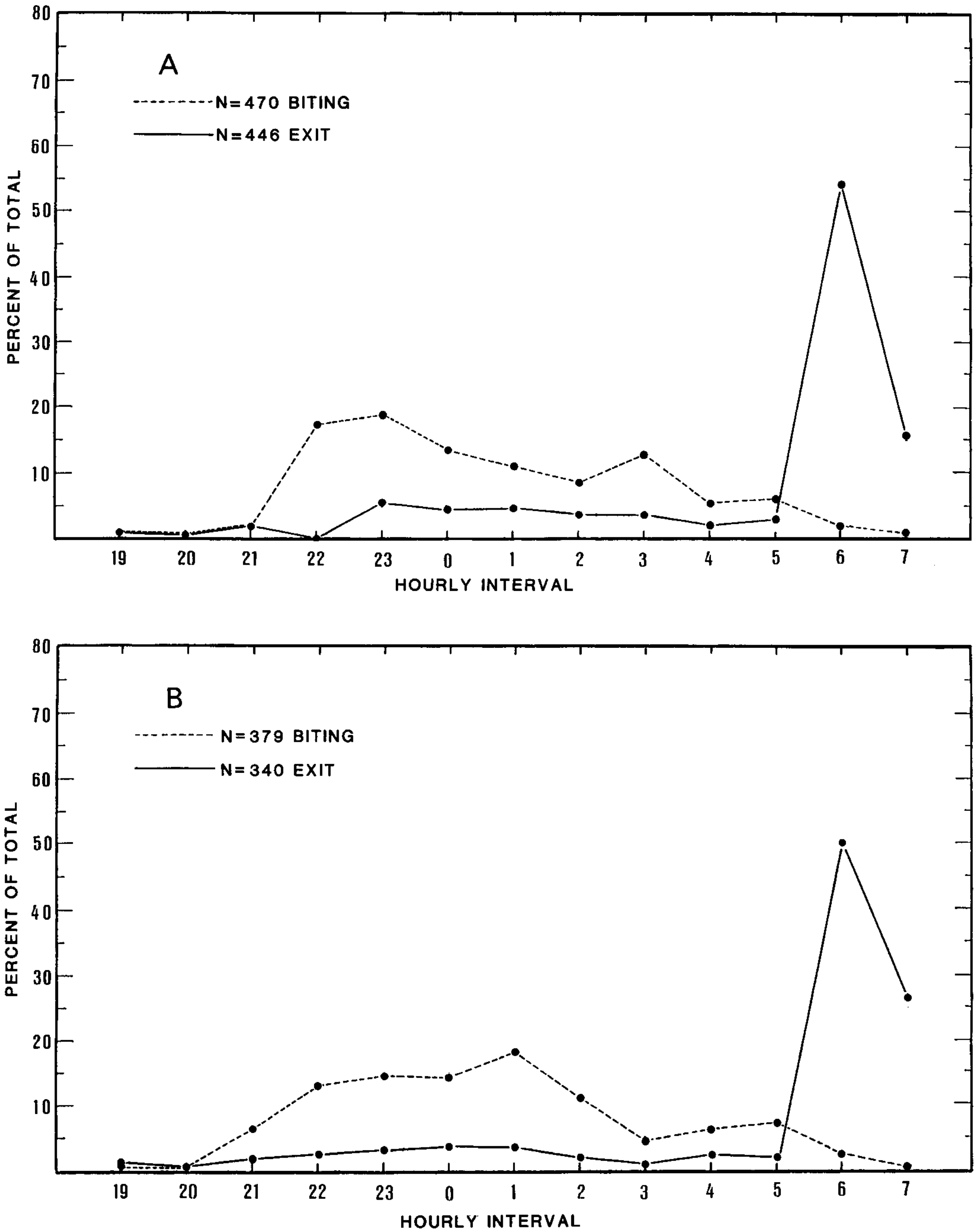

Fig. 3. Pre-spray comparison of biting and exit rates of *Anopheles darlingi* (42 nights of observation). A, test hut; B, control hut.

sprayed paper and the other with unsprayed paper. The upper lid was replaced by glass plates.

As with the previous test, 20–30 freshly fed *An. darlingi* were released in the box with the sliding partition in upward position and the two glass plates covered to darken the box. After 10 min the partition was let down quickly and the glass plates were uncovered to enable counting of the mosquitoes in each part.

RESULTS

Comparison of the two experimental huts before spraying: Data collected after 42 nights, from December 1984 to June 1985, of operating both experimental huts are shown in Fig. 3 and Table 1. There were minor differences in biting and exit rates between the huts, but the general tendencies were similar. In the test hut, 470 (11.2 per night) anophelines were counted while biting, in the control hut only 379 (9.0 per night). When testing the nightly totals with a sign test there appeared to be a statistically significant difference between the two huts ($t = 15$, $n = 37$, $P = 0.02$).

In exit trap collections 446 *An. darlingi* were collected from the test hut and 340 from the control hut, or 10.6 and 8.1 per night, respectively. Application of the sign test to the nightly totals of the exit trap collections showed that these data did not differ significantly ($t = 10$, $n = 38$, $P = 0.14$). Percentages fed (Sella's stage II) from the exit traps were 92.8% and 90.8%, respectively. In Table 1 the fortnightly totals collected in the exit traps of each hut are presented.

Association between numbers counted biting and collected before spraying: The high feeding success in the unsprayed test hut (92.8%) and the control hut (90.8%) makes it likely that most entering mosquitoes were counted while biting. The accuracy of this method in estimating the number of mosquitoes which entered is indicated by calculating the correlation coefficient between the nightly totals of the numbers of mosquitoes counted biting and the numbers in the exit traps in the 42 nights prior to the application of DDT to the test hut. The two variables appear to be significantly correlated ($r = 0.90$, $n = 42$, $P < 0.05$).

Table 1. Comparison between total number of *Anopheles darlingi* collected per fortnight in the exit traps of the test hut and the control hut in the prespray period.

Period of observation	No. of nights	Total number mosquitoes collected in exit traps from: Test hut	Control hut	Ratio total test hut/total control hut
Dec. 7–Dec. 20	4	34	35	0.97
Feb. 1–Feb. 14	2	17	16	1.06
Feb. 15–Feb. 28	6	23	26	0.88
Mar. 1–Mar. 14	6	55	16	3.43
Mar. 15–Mar. 28	6	29	28	1.03
Mar. 29–Apr. 11	5	28	29	0.96
Apr. 12–Apr. 25	6	47	50	0.94
Apr. 26–May 9	3	91	43	2.11
May 24–Jun. 6	2	60	36	1.66
Jun. 7–Jun. 20	2	62	61	1.01
Total	42	446	340	1.31

Effect of DDT spraying on biting, entry and exit behavior: Results of 32 nights of hourly exit trap collections and counting of biting mosquitoes following the spraying of the test hut with DDT are shown in Fig. 4. The number of anophelines biting in the test hut is less than in the control hut; 177 vs. 208 (5.5 vs. 6.5 per night). The biting activity patterns are similar with a biting peak in the late evening around 2300 h. The exit trap collections present different results for the two huts. Of 32 nights, only 15 yielded *An. darlingi* in the test hut with a total of 30, whereas in the control hut 25 nights yielded 247 specimens. A peak of exit from the control hut at dawn was not observed in the test hut collections. This can be explained by mortality of the mosquitoes in the test hut. A total of 110 dead *An. darlingi* specimens (76.4% fed) were collected on the floor in 23 of the 32 nights in the test hut.

The total number of mosquitoes collected in the control hut was equal to the numbers collected in the exit traps, i.e., 630 *An. darlingi* specimens (Table 2). The total number collected in the test hut was 295 specimens for the exit trap collections and floor collections combined. Although these figures suggest a reduction of entry rate by 53%, it should be taken into account that less mosquitoes were collected in the test hut than actually entered because some dead mosquitoes might have been removed by ants and irritated mosquitoes might have escaped through the entry openings. A more accurate estimate of the reduction in the entry rate is provided below.

Association between numbers counted biting and collected after spraying: In view of the reduced feeding success in the sprayed hut (72.3% in the period when mosquitoes were counted), it can be expected that the association between numbers counted biting and collected will not be as strong as shown above for the pre-spray situation. The same method for the calculation of the correlation coefficient can be applied when we add the numbers collected dead on the floor to the numbers collected in the exit traps. The numbers observed biting and collected are significantly correlated ($r = 0.67$, $n = 32$, $P < 0.05$).

EFFECT OF SPRAYING ON MORTALITY AND FEEDING SUCCESS OF AN. DARLINGI

Mortality: Four-weekly mortality figures of *An. darlingi* are presented in Table 2 for the test and the control hut. The test hut mortality is corrected with Abbott's formula for the control

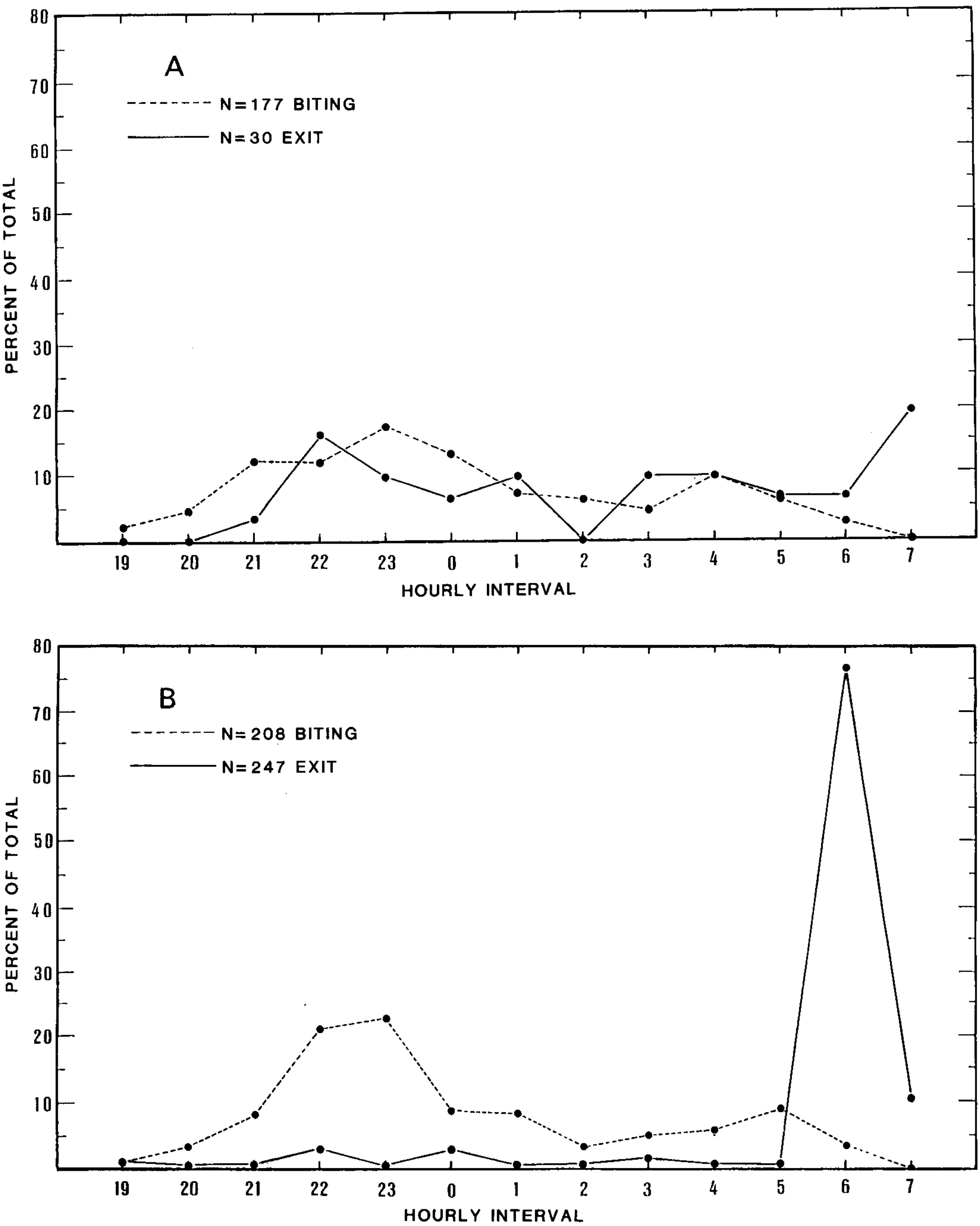

Fig. 4. Post-spray comparison of biting and exit rates of *Anopheles darlingi* (DDT-wettable powder; 32 nights of observation). A, test hut; B, control hut.

mortality when possible. For three periods no Abbott's correction was possible because the control mortalities were higher than 20%. The Abbott's corrected mortality over all periods together was 95.3%. Most of the mosquitoes died before leaving the hut (63.7%).

After December 1985 data collection became a serious problem due to a drop in the *An. darlingi* biting density, and for half of April operation of the experimental huts was stopped. The scarce information available for the last four months did not show a reduction in mortality in the test hut up to 10 months after spraying with DDT.

Feeding success: The total numbers of fed and unfed *An. darlingi* females collected in the test and control huts are presented in Table 3. Overall feeding success in the control hut was 89.0% and in the test hut 61.6%. In the test hut, only 51.3% of the mosquitoes collected in the exit trap were fed, whereas 68.4% of the mosquitoes collected dead from the floor were fed. In the period when biting mosquitoes were counted (wk 1–16), feeding success in both huts was higher compared to the situation when an assistant was sleeping in a hammock (wk 17–44).

The probability of an Anopheles darlingi *female entering a house, taking a blood meal and successfully exiting a sprayed house:* The impact of DDT sprayed housewalls on the number of mosquitoes entering a DDT treated house to feed can be calculated by applying Hudson's formula (Hudson 1984):

$$R = 100 \times \left(1 - \frac{\text{TnCo}}{\text{ToCn}}\right)$$

where

To = Average number counted per night while biting a human bait in the test hut on the nights before treatment.

Co = Numbers biting in the control hut before treatment.

Tn = Numbers biting in the test hut after treatment.

Cn = Numbers biting in the control hut after treatment.

By using the data from Table 4, a reduction of 32% is calculated in numbers coming to a human bait. The probability of a mosquito entering the sprayed house can thus be estimated at 0.68. Applying the same formula to the percentages of engorged mosquitoes in the exit traps, the probability of a mosquito taking a blood meal in the sprayed hut can be estimated at 0.56. Using the formula for *R*, a 90.7% reduction in numbers collected in exit traps in the sprayed house is calculated. However, this figure does not account for the reduced number of females that

Table 2. Post-spray mortality of *Anopheles darlingi* per period of four weeks after spraying the test hut with DDT-wettable powder.*

		Test hut				Control hut		
		Exit trap collection				Exit trap collection		
Period of observation	No. of nights	Total	24 h dead	Floor coll. total	Corrected mortality (%)	Total	24 h dead	Mortality (%)
Jun. 11–Jul. 8	1	2	2	12	100.0	37	4	10.8
Jul. 9–Aug. 5	10	7	6	66	98.5	25	2	8.0
Aug. 6–Sep. 2	7	10	7	15	—	44	16	36.4
Sep. 3–Sep. 30	13	11	10	14	95.2	73	12	16.4
Oct. 1–Oct. 28	17	48	44	23	—	243	55	22.6
Oct. 29–Nov. 25	17	17	16	18	96.6	99	16	16.2
Nov. 26–Dec. 23	15	6	6	24	—	34	12	35.3
Jan. 21–Feb. 17	15	0	0	3	100.0	19	3	15.8
Feb. 18–Mar. 17	19	1	0	7	85.8	33	4	12.1
Mar. 18–Apr. 14	14	5	5	3	100.0	21	1	4.8
Apr. 15–May 12	1	0	0	3	100.0	2	0	0.0
Total	129	107	96	188	95.3	630	125	19.8

* The 24 h mortality of mosquitoes collected from the exit traps was assessed. The overall test hut mortality was corrected for the control mortality with Abbott's formula when possible.

Table 3. Feeding success of *Anopheles darlingi* in the DDT-wettable powder sprayed test hut and control hut.*

	Test hut					Control hut	
	Floor collection		Exit trap collection		Both coll.	Exit trap collection	
Period of observation	Total	% fed	Total	% fed	% fed	Total	% fed
Wk 1–16	95	76.8	24	54.2	72.3	155	96.8
Wk 17–44	82	58.5	91	50.5	54.3	400	86.0
Wk 1–44	177	68.4	115	51.3	61.6	555	89.0

* The first 16 weeks (25 nights of observation) a human bait counted all biting mosquitoes. After week 16, the human bait slept unprotected from bites in a hammock (92 nights of observation).

Table 4. Nightly averages for numbers of *Anopheles darlingi* observed biting on human bait and collected in the exit trap and the percentages fed of the totals collected in the exit traps.

	Pre-spray		Post-spray	
	Test	Control	Test	Control
Human bait	11.2	9.0	5.5	6.5
Exit trap	10.6	8.1	0.9	7.7
Percent fed	92.8	90.8	51.3	89.0

had entered the sprayed house. A more realistic estimator is obtained by calculating the percentage of numbers observed coming to a human bait that were collected in the exit traps, i.e., 0.17% (0.94:5.5). The probability of a mosquito being able to escape the DDT sprayed house can thus be estimated at 0.17. This approach can be justified by calculating the concordance between the human bait and exit trap collection estimators. The concordance can be determined by

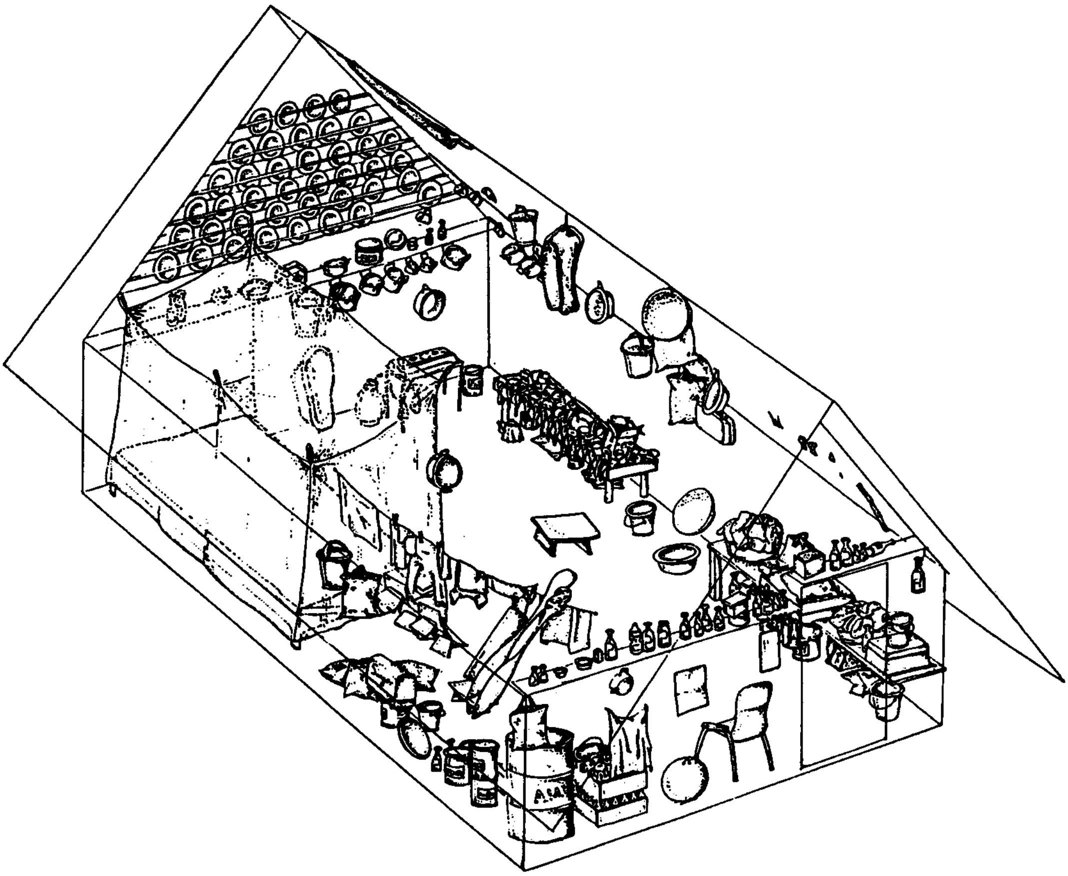

Fig. 5. Average furnished hut of a bush negro family consisting of a mother and her children. Hammocks and hammock mosquito nets which are unrolled at night, are not shown in this figure. The experimental huts were furnished accordingly.

Table 5. Total number of *Anopheles darlingi*, mortality and feeding success in the first 3 months after spraying the test hut with DDT emulsion concentrate (35 nights of observation).

Furnished test hut							Furnished control hut		
Floor collection		Exit trap collection			Total		Exit trap collection		
Total	% fed	Total	% fed	% mortality	% fed	% mortality	Total	% fed	% mortality
96	56.3	38	39.5	71.1	51.5	90.9	177	85.9	9.6

summing the respective values for the test and control huts pre-spray and the control house post-spray, i.e., 26.7 (11.2 + 9 + 6.5) and 26.4 (10.6 + 8.1 + 7.7). Thus by calculating 26.4:26.7, a very high concordance of 99% is found between these two population estimators.

Consequently, the probability of a mosquito entering a house, taking a human blood meal and successfully exiting a house after it is sprayed with DDT is 0.065 (= 0.68 × 0.56 × 0.17). Based on the results of the bioassay tests and the mortality rates in the exit traps of the sprayed house, the probability of surviving more than 24 h after exiting the sprayed house is virtually zero.

Effect of DDT spraying in a furnished house: The "average" quantity of items per house, based on inventory of eight bush negro houses, is shown in Fig. 5, and served as a guide for furnishing the test and control huts. In Table 5 the results are shown for 35 nights of operation of the test and the control hut. Due to political problems the study had to be interrupted after three months. During the three months of operation the biting density was again very low. In the control hut, 5.1 *An. darlingi* specimens were observed per night, with a total of 177 specimens collected in exit traps. Compared to the mortality in the unfurnished test hut, there was a small reduction in mortality in the furnished test hut. The Abbott's corrected mortality over the total period was 90.9%. Feeding success in the test hut was 51.5% and in the control hut 85.9%. This was comparable with the feeding success in wk 17–44 (Table 3) in the unfurnished huts, during which period the operations were similar.

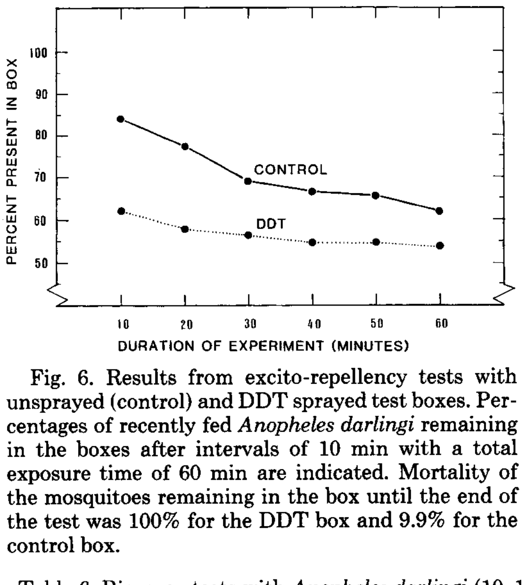

Fig. 6. Results from excito-repellency tests with unsprayed (control) and DDT sprayed test boxes. Percentages of recently fed *Anopheles darlingi* remaining in the boxes after intervals of 10 min with a total exposure time of 60 min are indicated. Mortality of the mosquitoes remaining in the box until the end of the test was 100% for the DDT box and 9.9% for the control box.

Residual effect of DDT in a sprayed hut: Results of bioassay tests of DDT wettable powder and DDT emulsion concentrate are shown in Table 6. Six months after the test hut was sprayed with DDT wettable powder, the bioassays could not be performed because of a scarcity of test mosquitoes. Low mortalities during the fifth and sixth months from thatched roof sites were probably due to loss of DDT deposits when removing the cones during the previous test. For the test in the 15th month another test site was selected, and mortality was similar to that encountered for other test surfaces.

Results of the excito-repellency tests: In Table 7 (see also Fig. 6) the combined results of six replicates of the excito-repellency tests with an unsprayed and six replicates with a sprayed test box are presented. In the beginning escape rates were highest from the sprayed box, but after 20 min almost no additional escapes were observed. We believe that most mosquitoes in the sprayed

Table 6. Bioassay tests with *Anopheles darlingi* (10–15 per cone) exposed for 30 min on a wooden wall and thatched roof in the test hut sprayed with DDT-wettable powder, the test hut sprayed with DDT-emulsifiable concentrate and the unsprayed control hut.*

DDT formulation	Months after spray	Test hut sprayed with 2 g/m²				Control hut			
		Wall		Roof		Wall		Roof	
		No. tests	Corr. mort.	No. tests	Corr. mort.	No. tests	Corr. mort.	No. tests	Corr. mort.
Wettable powder	1	2	95.4			2	13.5		
	2	2	95.4	2	100.0	1	13.3	1	13.3
	3	3	100.0	2	100.0	2	5.0	1	7.1
	4	2	100.0	4	87.6	1	13.3	2	7.5
	5			2	56.6			1	17.0
	6	2	96.5	1	39.0	1	0.0	1	18.0
	15	2	100.0	1	100.0	1	9.1	1	6.7
Emulsifiable concentrate	1	1	100.0			1	10.0		
	2	1	83.5			1	6.7		
	3			1	100.0			1	6.7

* The 24-h delayed mortality is corrected for the control mortality with Abbott's formula.

Table 7. Results from excito-repellency tests with unsprayed and DDT-wettable powder sprayed testboxes.*

Type of test box	Mosquitoes remaining in test box; % of total number						No. still in box; 1 h			Total no.	No. of repl.
	10	20	30	40	50	60	Alive	Dead	% dead		
Control	84.2	77.4	69.2	66.4	65.1	61.6	82	9	9.9	146	6
Sprayed	62.6	57.7	56.4	54.6	54.6	54.0	0	88	100.0	163	6

* Percentages of recently fed *Anopheles darlingi* remaining in the boxes after intervals of 10 min with a total exposure time of 1 h are presented, together with the number of living and dead mosquitoes in the boxes at the end of the experiment.

box died within the first 20 min. At the end of the test, 100% of all mosquitoes still in the box were dead. In the unsprayed box most mosquitoes left the box within 30 min. Only 9.9% of the mosquitoes that remained in the box for 1 h were dead.

Choice box experiment: Ninety-eight freshly-fed *An. darlingi* specimens were tested in four separate tests of 20–30 specimens each. After 10-min exposure a total of 52 *An. darlingi* specimens were counted in the unsprayed box and 46 in the sprayed box.

DISCUSSION AND CONCLUSIONS

We have demonstrated that DDT house-spraying can be effective in spite of the short indoor resting period of *An. darlingi* in Suriname. This must be due to a high susceptibility of *An. darlingi* to DDT because in most other malarious areas a longer indoor resting period seems necessary. The type of sprayed surface is also an important factor, and both the thatched roof and the wooden wall of unpainted timber absorbs far less DDT than the mud-plastered walls used in other areas of the world. However, painted walls might be unfavorable for spraying because the DDT deposits can easily be washed off or otherwise removed.

Both the bioassay tests and the mortality figures showed that DDT wettable powder sprayed on a wooden wall or thatched roof remained effective for a period of at least one year. No data are available about the residual efficacy of DDT emulsion deposits after more than three months, but the probabilities are high that the residual activity is similar considering the similarities in data of the first three months for wettable powder and emulsion concentrate assays. Because at present bush negroes accept spraying only with the emulsifiable formulation of DDT in their houses, it is important to verify the residual efficacy of several dosages.

From the choice box experiments it seems that *An. darlingi* is not able to discriminate between sprayed and unsprayed surfaces. This is in agreement with the high mortality figures in the furnished test hut.

The higher escape rate from the DDT treated excito-repellency test box might be due to an irritant effect of DDT which activates the mosquito in a selective way and causes disorientation. In the control box the mosquitoes are not agitated and readily come to rest in the box. The low escape rates of mosquitoes from both the furnished and unfurnished sprayed experimental huts might be explained by disorientation and the lower chance in a hut to enter an exit trap by random movements.

The lower number of mosquitoes collected in the sprayed hut when compared to the control hut suggests a reduction of entry due to the presence of DDT deposits. Possibly, this deterrent effect, which reduces entry, is exerted by the DDT deposits on the outer wall and on the roof near the upper inlet slit. However, the figures on a reduction of the entry rate have to be considered with caution. Dead mosquitoes might have remained undetected, or been removed by ants; moreover, the huts differed slightly in attraction to mosquitoes during the prespray period.

When considering the relatively high feeding success in a sprayed hut (61.6%), it is probable that most mosquitoes attack immediately after entering the hut before they become irritated and killed by the DDT. This is also demonstrated by the similarity between biting patterns in the control and test hut.

The behavior of *An. darlingi* in relation to DDT appears to vary within the region. In Guyana, Symes and Hadaway (1947) found a behavior corresponding to our data. *Anopheles darlingi* entered a sprayed hut and attacked immediately afterwards, but after contact with DDT-treated surfaces they tried to escape without attempting to bite. Charlwood and Paraluppi (1978) and Roberts et al. (1984) along the Ituxi in Amazonas, Brazil, observed high escape rates for *An. darlingi* from DDT-treated repellency boxes. In the latter case only about 20–25% of recently fed females remained in the box after one hour. With experimental houses Roberts et al. (1984) found such a high level of DDT avoidance that *An. darlingi* rarely entered sprayed houses. Differences in study design might be partly responsible for the higher escape rates observed in Brazil as compared to Suriname. Kennedy (1947) demonstrated increased positive phototaxis in mosquitoes irritated by DDT. Possibly more *An. darlingi* escaped from the boxes used in the tests of Charlwood and Paraluppi (1978) and Roberts et al. (1984) than in the tests in Suriname because the Brazilian studies were conducted in the daytime and the exit traps were more brightly lit.

In Minas Gerais, Brazil, de Bustamente et al. (1952) found in sprayed houses a reduction in feeding success of 70%. In this area *An. darlingi* discontinued indoor resting after spraying of houses (Giglioli 1956). In the south of Venezuela, Pintos (1975) observed a rapid avoidance by *An. darlingi* of DDT with the standard WHO irritability test. According to Sucre (1982, in a report for a border meeting on malaria at Cayenne, French Guyana), this behavior makes *An. darlingi* less vulnerable to indoor residual spraying. Pintos (1975) therefore recommended spraying of houses with either HCH or dieldrin rather than with DDT. Elliott (1972) found in Colombia, after spraying a house, a shorter resting period for *An. darlingi* and an overall mortality of 72% of the entering mosquitoes.

In all areas a certain level of irritability is found but no resistance to DDT. Possibly the availability of safe outdoor resting places in the usually forested environment prevented the development of a DDT-resistant strain of *An. darlingi.*

The shape of houses seems to play a role, and it is likely that an irritated and possibly disoriented mosquito escapes more easily from an open house than from a house with almost no openings like the bush negro houses in Suriname.

Important successes with DDT house-spraying so far were only achieved in the coastlands of Guyana and Venezuela (Giglioli 1956). As stated by Giglioli (1948) for *An. darlingi* in the coastland, houses provided the only safe resting places. This made it easier to eradicate *An. darlingi.* In all other, forested areas the existence of "wild" *An. darlingi* populations outside human settlements made eradication impossible. Regardless, control of malaria through vector oriented measures might still be possible. In Suriname *An. darlingi* densities are low, and only a small reduction of vector capacity might result in a drop in malaria incidence.

Where residual spraying is envisaged, the two spraying cycles per year could be reduced to only one because the residual activity of the DDT deposits last about one year. Thus, an increase in the quality and coverage of spraying could be achieved. However, we should remember that the killing potency of DDT may be lower in occupied houses because of activities that diminish the quantity of DDT, such as washing walls, burning fires inside the house, etc. In Amerindian villages in the south of Suriname, spraying with wettable powder is generally accepted; but the open structure of the houses might reduce the effectiveness of DDT house spraying.

ACKNOWLEDGMENTS

We wish to thank Dr. M. Nathan, PAHO-entomologist, Dr. J. E. Hudson, Prof. Dr. H. J. van der Kaay, Institute for Parasitology, Leiden, and Prof. Dr. J. J. Laarman, Royal Tropical Institute, Amsterdam, for their advice; Dr. L. M. E. Jozefzoon, Bureau of Public Health, for providing the necessary manpower, P. Poetisie and his entomological team for their conscientious work and staff and personnel of the Medical Mission for their cooperation. Finally, we thank the research finance committee of the Office for International Cooperation and the Student Advisers of Leiden University, The Netherlands, for their financial support to the coauthors J. P. M. van Hoof and J. Voorham.

REFERENCES CITED

Barnes, T. and C. D. Jenkins. 1972. Changing personal and social behaviour: experiences of health workers in a tribal society. Soc. Sci. & Med. 6:1–15.

Bruce-Chwatt, L. J. 1971. International conference on alternative insecticides for vector control. Bull. W.H.O. 44:406.

Charlwood, J. D. 1980. Observations on the bionomics of *Anopheles darlingi* Root (Diptera: Culicidae) from Brazil. Bull. Entomol. Res. 70:685–692.

Charlwood, J. D. and N. D. Paraluppi. 1978. O uso de caixas excito-repelentes com *A. darlingi* Root, *A. nuneztovari* Gabaldon e *Culex pipiens quinquefasciatus* Say obtidos em áreas perto de Manaus, Amazonas. Acta Amazonica 8:605–611.

de Bustamente, F. M., O. S. Pinto and J. R. De Freitas. 1952. Observaçoes sôbre o comportamento do *A. darlingi* em casas experimentais tratadas com DDT e BHC na área de Engenheiro Dolabela, Estado de Minas Gerais. Rev. Bras. Malariol. Doenças Trop. 4:347–359.

Elliott, R. 1972. The influence of vector behavior on malaria transmission. Am. J. Trop. Med. Hyg. 21:755–763.

Giglioli, G. 1948. An investigation of the house-frequenting habits of mosquitoes of the British Guyana coastland in relation to the use of DDT. Am. J. Trop. Med. 28:43–70.

Giglioli, G. 1956. Biological variations in *Anopheles darlingi* and *Anopheles gambiae.* Their effect on practical malaria control in the neotropical region. Bull. W.H.O. 15:461–471.

Hudson, J. E. 1984. *Anopheles darlingi* Root (Diptera: Culicidae) in the Suriname rain forest. Bull. Entomol. Res. 74:129–142.

Kennedy, J. S. 1947. The excitant and repellent effects of mosquitoes of sublethal contacts with DDT. Bull. Entomol. Res. 37:593–607.

Pintos, P. A. 1975. Comportamiento de *A. darlingi* en presencia de DDT en el Dpto. Atares, del T. F. Amazonas. Dirrecion de Malariologia, Maracay. Unpublished report, 20 pp.

Rachou, R. G., L. A. Schinazi and M. M. Lima. 1973. An intensive study of the causes for the failure of residual DDT spraying to interrupt the transmission of malaria in Atalaya and Falla, two villages on the coastal plain of El Salvador, Central America. Rev. Bras. Malariol. Doenças Trop. 25:5–293.

Roberts, D. R., W. D. Alecrim, A. M. Tavares and K. M. McNeill. 1984. Influence of physiological condition on the behavioral response of *Anopheles darlingi* to DDT. Mosq. News 44:357–362.

Rozendaal, J. A. 1987. Observations on the biology and behaviour of anophelines in the Suriname rainforest with special reference to *Anopheles darlingi* Root. Cah. ORSTOM, Ser. Entomol. Med. Parasitol. 25:33–43.

Rozendaal, J. A. 1989. The biting and resting behavior of *Anopheles darlingi* in the Suriname rainforest. J. Am. Mosq. Control Assoc. 5:351–358.

Symes, C. B. and A. B. Hadaway. 1947. Initial experiments in the use of DDT against mosquitoes in British Guyana. Bull. Entomol. Res. 37:399–430.

World Health Organization (WHO). 1975. Manual of practical entomology in malaria. Parts I & II. WHO Offset Publications No. 13:1–160.