Bull. Org. mond. Santé
Bull. Wld Hlth Org. } 1963, 29, 131-145

Ecological Change as a Factor in Renewed Malaria Transmission in an Eradicated Area

A Localized Outbreak of *A. aquasalis*-transmitted Malaria on the Demerara River Estuary, British Guiana, in the Fifteenth Year of *A. darlingi* and Malaria Eradication

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In British Guiana, the successful eradication of Anopheles darlingi *and malaria from the coastal areas has caused a very rapid increase in the population and has favoured a considerable social and economic improvement and expansion of both agriculture and industry. Housing and industrial developments and the constantly expanding rice cultivation have taken over most of the accessible pasture-lands, displacing the livestock which previously abounded around villages and settlements. Mechanization on the roads and in the fields increases daily, and the horse, the mule, the donkey and the ploughing oxen are gradually becoming obsolete.*

In some areas these changes have already caused such an upset in the balance between the human and the livestock population that A. aquasalis, *a very abundant species all along the coast, but until recently entirely " fixed " by the livestock population, is now shifting its attention from livestock to man. On the Demerara river estuary, an area where malaria transmission was interrupted sixteen years ago and where eradication has been continually maintained, this mosquito has been responsible for a sharp, but localized, outbreak of* P. vivax *malaria. An entirely new epidemiological problem thus presents itself.*

Environmental changes, introduced and fostered by successful malaria eradication, may thus cause an anopheline species, potentially capable of malaria transmission, but originally inactive and harmless as a vector, to alter its feeding habits and thereby renew transmission. The immediate and long-term significance of some secondary and potential vectors may therefore require renewed evaluation in the planning of malaria eradication campaigns.

MALARIA TRANSMISSION IN COASTAL BRITISH GUIANA BEFORE THE ADVENT OF DDT AND THE ERADICATION OF *A. DARLINGI* AND MALARIA

In the Guiana coastal areas, *Anopheles darlingi* and *A. albitarsis* were first differentiated from each other and properly identified in 1934 (Giglioli, 1938a); but the " *A. tarsimaculatus* " species complex was not sorted out until 1943, so that in our earlier reports both *A. aquasalis* and *A. triannulatus* were grouped under that name. *A. triannulatus*, however, is not a frequent species on the coast and practically never enters houses; what was identified as *A. tarsimaculatus*, in our earlier reports on anopheline house captures, may therefore confidently be re-labelled *A. aquasalis.*

A. albitarsis is very common in rice-fields and savannahs, both on the coast and in the interior. It enters houses rarely, usually in search of shelter during evening or early morning rain-storms; specimens collected resting in houses are usually unfed.

A. aquasalis is an established malaria vector along the north-east coast of South America, and in some of the Caribbean islands. In British Guiana, however, its role as a vector was much more doubtful, malaria being absent or rare in the areas where it was most abundant.

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As early as 1938 (Giglioli, 1938b) we reached the conclusion that *A. darlingi*, a selectively anthropophilic and endophilic species, was the only vector of practical importance in the country; *A. aquasalis* and *A. albitarsis*, on the contrary, were strictly zoophilic and exophilic.

In a series of 15 036 anophelines captured in houses in 1934-37, between 6 a.m. and 9 a.m., mainly on the estuary of the Berbice river, we recorded:

A. darlingi . . .	99.1%
A. aquasalis . .	0.2%
A. albitarsis . .	0.7%

Conversely, in a series of 2699 adults captured in animal shelters and on horses in the open, we recorded:

A. darlingi . .	2.2%	(all from stables where grooms and watchmen were on duty at night)
A. aquasalis . .	59.9%	
A. albitarsis . .	37.9%	

In 1945 and 1946 observations were extended to the east and west coasts of Demerara (Giglioli, 1948a). In the aggregate, 122 428 mosquitos were collected during morning captures in houses and, of these, 31 714 were anophelines:

A. darlingi . . .	31 708
A. aquasalis . .	1
A. albitarsis . .	5
A. triannulatus .	0

The relative density of the populations of each species, during the same period, was revealed by systematic larval collections; these indicated that the density of the *A. aquasalis* population, as regards both numbers of breeding-places and numbers of larvae, was much the same as that of *A. darlingi*. In areas subject to frequent tidal salt water flooding, *A. darlingi* was rare or absent, while *A. aquasalis* was extremely abundant (Corentyne coast). The examination of 8320 potential breeding-sites (irrigation canals, rice-fields, cane-fields in flood fallow, drains, ponds, and swamps) gave the following results:

	Breeding-places	*Larvae*
A. darlingi	1 246	4 610
A. aquasalis	1 144	5 507
A. albitarsis	369	1 337
A. triannulatus	100	306

To establish the nocturnal biting habits and blood preferences of local *Anopheles*, captures were made in parallel at Lusignan Estate, on the east coast of Demerara, in two human-baited huts and in a calf-baited Shannon dawn trap; the results of these observations are summarized in Table 1. The anthropophilism of *A. darlingi* and the zoophilic propensities of *A. aquasalis* and *A. albitarsis* were fully confirmed.

TABLE 1

LUSIGNAN ESTATE: ALL-NIGHT CAPTURES IN HUMAN-BAITED EXPERIMENTAL HUTS AND IN A CALF-BAITED SHANNON DAWN TRAP, 1945-46

	Human-baited huts (2-hourly captures, 6 p.m. to 6 a.m.)	Calf-baited Shannon trap (6 p.m. to 6 a.m.)
No. and period of observations	32 (April-September 1945)	167 (April 1945 to July 1946)
Total *Anopheles*	1 111	5 408
A. darlingi	1 056 (95 %)	19 (0.35 %)
A. aquasalis	8 (0.7 %)	4 828 (89.2 %)
A. albitarsis	47 (4.0 %)	559 (10.3 %)
A. triannulatus	0 (0 %)	2 (0.03 %)
Other mosquitos	7 754	20 062
Total catch	8 865	25 470

During the period of maximum production (June-August), *A. aquasalis* is frequently attracted to brightly illuminated buildings, and may attack quite actively.

Up to the introduction of DDT, it was felt, on the evidence of the observations summarized above, that *A. darlingi* was *the* malaria vector; however, given the huge reservoir of infection maintained by this species it was considered likely that *A. aquasalis* and, less probably, *A. albitarsis* might be responsible for occasional or accidental malaria transmission. (Giglioli, 1948b.)

A. aquasalis is widely eclectic in its selection of breeding-sites, though it prefers salt or brackish water. Its range and prevalence, therefore, tend to vary according to the greater or lesser prevalence of such waters. In years of drought, while the prevalence of *A. darlingi* falls, *A. aquasalis* tends to become more abundant; during the very severe drought of 1939-40, when salt water had to be introduced into the sugar estate irrigation network to allow transportation of cane from the fields to the factories, *A. darlingi* temporarily disappeared and a remarkable remission of malaria was observed. *A. aquasalis*, on the contrary, became very abundant and was frequently captured in houses situated close to its

TABLE 2
BRITISH GUIANA COASTAL AREAS: CAPTURES OF *ANOPHELES* LARVAE, 1950-55

Year	No. of breeding-sites examined	*A. darlingi*		*A. aquasalis*		*A. albitarsis*	
		Foci	Larvae	Foci	Larvae	Foci	Larvae
1950	12 089	0	0	2 666	10 559	3 162	15 686
1951	15 009	0	0	3 515	13 023	2 302	19 566
1952	11 760	0	0	2 151	10 910	1 120	4 902
1953	5 528	0	0	801	4 593	663	4 060
1954	5 920	0	0	1 115	6 958	657	2 677
1955	9 264	0	0	924	5 869	723	4 768
Total	59 570	0	0	11 172	51 912	8 627	51 659

breeding-sites. However, out of a series of 2641 females thus collected, no less than 67% had not fed recently.

During dry periods, tidal salt water invasion of the estuaries and lower reaches of the rivers extends far beyond the average level; thus, not only the prevalence of *A. aquasalis*, but its range as well, is increased.

Malaria was never heavily endemic on the lower, mangrove-fringed reaches of the many large rivers of the North-West District, subject to periodical, tidal salt water invasion. *A. darlingi* was not found; surface water conditions (brackish or very acid, peaty waters) were obviously unfavourable for this species. *A. aquasalis* was abundant and, given the nearly complete absence of livestock in this area, much more domestic in its feeding habits; it maintained a low malaria endemicity, with spleen rates usually below 15%. In this area, the epidemiology of malaria was thus more similar to that in the coastal plains of Surinam and Trinidad.

EFFECT OF THE DDT CAMPAIGN (1946-50) ON THE VARIOUS ANOPHELINE SPECIES OF THE COASTAL AREAS

In British Guinea, DDT was used exclusively as a house spray and no antilarval techniques were employed. The adult *A. darlingi*, converging on the houses from the immense breeding-area in the irrigation canals, rice-fields, cane-fields in flood-fallow, drains, ditches, etc., constituted our specific target.

The effects of systematic blanket spraying were immediate and dramatic: *A. darlingi* disappeared both from the houses and from its habitual breeding-grounds. There was no change whatsoever in the population of either *A. aquasalis* or *A. albitarsis*, as indicated by the routine larval collections made between 1950 and 1955 (Charles, 1950-55) and summarized in Table 2.

During the same period *A. aquasalis* and *A. albitarsis* continued to be collected only occasionally in the course of routine morning house captures, as shown in Table 3; their selective exophilic and zoophilic feeding habits appeared unchanged.

MALARIA INCIDENCE AFTER THE ERADICATION OF *A. DARLINGI*: 1950-61

Coastal areas

Chemotherapeutic techniques were at no time applied in the course of our 1946-50 eradication campaign. Our only aim was to interrupt transmission, and this aim was successfully attained.

Before the inauguration of the campaign (1943-45) the average spleen rates among children in rural schools were approximately as follows (Giglioli, 1948b):

East Demerara	42%
West Demerara	40%
Essequibo islands	35%
Essequibo coast	70%

It is obvious that, after the eradication of *A. darlingi* was achieved, a huge reservoir of *Plasmodium* infections still persisted for many months; these infections extinguished themselves gradually by unaided, natural recovery processes. By 1950, all evidence of malaria had disappeared from the densely

TABLE 3

BRITISH GUIANA COASTAL AREAS: MORNING CAPTURES OF ADULT MOSQUITOS IN HOUSES, 1950-55

Year	No. of houses examined	Total captures (all species)	*A. darlingi*		*A. aquasalis*		*A. albitarsis*	
			No. caught	Average catch per house	No. caught	Average catch per house	No. caught	Average catch per house
1950	12 928	106 054	0	0.0	45	0.004	13	0.010
1951	20 225	59 144	0	0.0	354	0.017	200	0.009
1952	19 936	162 220	0	0.0	661	0.033	51	0.002
1953	10 102	174 827	0	0.0	271	0.026	70	0.006
1954	12 662	311 290	0	0.0	234	0.017	59	0.004
1955	9 412	88 080	0	0.0	150	0.016	130	0.013
Total	85 265	901 615	0	0.0	1 715	0.020	523	0.006

populated coastal areas, and spraying operations were closed down in 1951 (Giglioli, 1951); with one isolated exception in April 1955, no case of locally acquired malaria was recorded for 10 years, till July 1961. This progressive extinction of some hundreds of thousands of actual malaria infections throughout the coast took place in spite of the continued presence of large populations of *A. aquasalis* and *A. albitarsis*; neither of the last-mentioned species proved capable of perpetuating the infection even at only a low level of endemicity.

Interior

In the interior, the campaign proceeded more slowly and with much greater difficulty. Eradication was achieved over most of the more accessible and densely populated areas along the lower reaches of the Essequibo, Demerara, Berbice and Corentyne rivers. In the vast, sparsely inhabited and inaccessible districts of the remote interior, particularly along the Brazilian border, malaria infection persisted, even though the incidence had been drastically reduced. Spraying operations in the interior were therefore continued on an annual cycle, this being regarded as less expensive and more efficient than the setting up of a complex surveillance organization which could never be adequately supervised.

The reasons for this failure of our eradication campaign in the remote interior (Giglioli, 1959) can be easily summarized.

1. The difficulty of locating all habitations and camps in the forest.

2. The habitual and frequent displacements of the Indian population from their permanent settlements to temporary shelters and camps on their farms in the forest.

3. The exophily of *A. darlingi* and its persistence in semi-inhabited forest.

4. The lack of adequate sprayable surfaces in the rudimentary house structures used on the farms and in bush camps.

5. The difficulty of access, particularly in the wet season, when flooding interrupts lines of communication, and in the dry season, when the upper reaches of many of the rivers become unnavigable even for small boats.

6. The impossibility of ensuring adequate supervision.

7. The complete lack of antimalarial provisions, up to 1960, in the Brazilian territory adjoining our border.

Thus, though malaria cases became rare and the general health of the population improved immeasurably, giving rise to a rapid and truly impressive population increment, scattered foci of infection remained in the North-West District, the Upper Cayuni, Mazaruni and Potaro rivers, in the Rupununi savannahs and around the headwaters of the Essequibo. More or less regular and rapid communications now exist between the densely populated coastlands and all these areas.

In the five years between 1950 and 1954, the Mosquito Control Service Laboratory identified, in the aggregate, 277 positive cases, all originating from known infected areas of the interior or from outside the country. The records from 1955 to 1959 are not satisfactory, and it is felt that the standard of microscopy was inadequate.

In 1955, an outbreak was recorded along the Brazilian border in the North Rupununi savannah. Out of 200 blood slides examined, 62 were positive for either *P. falciparum* (67%) or *P. vivax* (33%); *A. darlingi* was also collected. Spraying in this area had been neglected since 1952, and none had ever been done across the border.

In 1958-59, an outbreak of *A. aquasalis*-transmitted malaria occurred in the lower reaches of the many rivers in the North-West District, extending along the Barima estuary into Venezuelan territory, an eradicated area. Two factors caused this outbreak: (*a*) irregular and poor spraying operations; (*b*) the persistent low rainfall since 1957 (see Table 4), which resulted in a reduction in the flow of all rivers so that the tidal invasion of salt water extended over a much wider area than normal, greatly increasing the range, numbers and persistence of *A. aquasalis*.

A total of 64 positive cases was recorded (*P. vivax*, 31; *P. falciparum*, 26; *P. malariae*, 5; mixed infections, 2) from the lower Barima, Kaituma, Aruka, Waini, Moruca and Pomeroon rivers; there is little doubt, however, that the actual number of cases was much higher.

By carefully supervised, six-monthly spraying and systematic chemotherapy, this outbreak was controlled; in 1960 there were 51 cases in this area and in 1961 there were only four.

Early in 1949, no evidence of malaria was collected during a visit to the upper Kaituma and Barima, where a large construction labour force was at work, building important manganese mining installations and 30 miles (about 50 km) of railway. These areas are far above the limit of salt water and *A. aquasalis* inland penetration. An outbreak of fever, however, occurred in this area in the latter part of 1959, and at one time some 30 people with fever were reporting

TABLE 4

ANNUAL AND MONTHLY RAINFALL ON THE COAST (GEORGETOWN) AND IN THE NORTH-WEST DISTRICT (LOWER BARIMA RIVER)

Year	Monthly rainfall (inches [a])												Annual rainfall (inches [a])
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
A. Coastal area: Georgetown, Botanical Gardens Station													
Mean 1882-1955	9.32	5.64	5.88	6.53	11.68	12.71	10.63	6.77	3.11	2.92	5.72	12.06	92.97
1956	8.58	3.80	6.63	4.43	14.46	12.99	15.71	12.99	13.60	4.60	5.76	17.35	120.90
1957	5.14	1.56	0.17	1.74	11.49	8.54	9.33	1.83	0.89	2.42	4.06	12.02	55.19
1958	2.39	3.83	3.22	15.93	5.54	13.25	3.51	4.91	0.36	4.91	0.69	3.29	61.83
1959	4.47	2.20	0.70	2.75	2.83	21.30	8.41	11.14	2.16	5.34	6.36	9.79	78.45
1960	6.51	1.79	2.67	5.28	13.98	12.60	11.02	9.07	1.95	3.87	6.46	8.70	83.90
1961	4.39	2.09	0.81	0.50	4.41	14.83	10.10	10.17	1.69	2.53	5.16	6.28	62.96
B. North-West District: Lower Barima River, Morawhanna Station													
Mean 1907-1955	9.55	5.57	4.65	6.38	12.68	15.84	12.79	10.02	6.96	6.81	8.93	15.02	115.18
1956	14.20	8.93	6.31	6.68	18.55	16.73	10.33	9.12	8.24	19.59	5.60	29.60	154.18
1957	13.55	3.07	1.83	1.05	5.88	8.78	8.97	5.47	7.18	3.25	20.40	13.73	93.16
1958	4.90	3.66	1.72	7.09	9.10	11.71	11.57	10.59	4.25	8.44	3.70	4.51	81.24
1959	7.40	5.31	1.84	1.60	7.02	15.94	12.68	12.30	4.87	10.86	10.82	9.06	99.70
1960	2.89	1.12	0.43	8.90	8.61	13.49	12.15	10.18	3.22	6.67	14.09	7.25	89.00
1961	7.32	1.93	0.61	0.48	6.02	11.35	11.99	9.82	9.91	6.60	9.99	6.41	82.43

[a] 1 inch = 25.4 mm.

to the mine's dispensary daily. The outbreak, however, was not reported to the Mosquito Control Service until April 1960, when an immediate survey was undertaken and, out of 756 slides examined, 56 were found positive (*P. falciparum*, 30; *P. vivax*, 17; *P. malariae*, 0; mixed, 9). *A. darlingi* were collected in the houses at several points throughout the area. This species had obviously survived on the upper Barima, around and above Arakaka, as this area was rarely sprayed owing to its previous inaccessibility and very small population. Malaria parasite carriers were probably introduced from the lower Barima and Kaituma early in 1959. Systematic spraying and chloroquine treatment rapidly controlled this outbreak. Primaquine does not appear to have been used.

In the latter part of 1959, while this malaria outbreak was at its peak, the construction of the manganese mining plant was completed; some 700 construction personnel were laid off and returned to the coast between November 1959 and April 1960. It is estimated that 25% of these workers returned to Georgetown, 25% to the Mackenzie bauxite mines and 50% to the coastal rural villages and sugar estates. Thus, presumably, a considerable number of infected persons reached the coast and became dispersed over a wide area, early in 1960.

This brief history outlines the distribution and entity of malaria infection in the interior (population, approximately 45 000) over past years; it is evident that the influx of parasite carriers into the eradicated coastal area, though not great, must have been fairly continuous over the past decennium, with substantial increases in 1959 and 1960. It is likely that the chloroquine treatment given at the manganese mines sterilized most of the *P. falciparum* infections. Primaquine, however, was not used; this may account for the survival of *P. vivax* which, as will be seen, was the only species to reach the coast.

Since January 1961, chloroquinized salt has been supplied to all inhabited remote areas of the interior, with excellent coverage and promising results. We are not yet in a position, however, to form a firm opinion on the ultimate effectiveness of this relatively new technique; conditions along the Brazilian frontier remain unsatisfactory.

RECURRENCE OF MALARIA ON THE DEMERARA RIVER ESTUARY IN 1961

Extent and entity of outbreak

On both banks of the Demerara river estuary, DDT-spraying operations were begun in 1946 and concluded in 1950. From 1951, spraying was discontinued along the coast and on the lower part of the estuary; barrier spraying, as a precaution against *A. darlingi* re-invasion from the interior, was continued south of Grove village and of Canal Polder No. 2. The many extensive housing layouts which have developed on both banks since 1950 were never sprayed. *A. darlingi* disappeared from the area at the end of 1946, and malaria in 1948.

The first case recorded in 1961 was diagnosed in Diamond Estate hospital on 21 July, in an East Indian boy, 16 years old, who had resided at Grove housing settlement for the past 8 years and had a negative history as regards residence in or visits to any other area. His blood showed a mixed infection with *P. vivax* and *P. malariae*. On 31 July, the Mosquito Control Service Laboratory recorded the first cases from the west bank of the estuary—one at Canal Polder No. 2 and the other, diagnosed from a slide taken on 25 July, from Sisters village.

Systematic investigations were immediately instituted on both river banks, to identify other cases, to establish the extent and entity of the outbreak, and to determine its origin and the vector species responsible. Between July 1961 and June 1962, a total of 89 cases was discovered; all were *P. vivax* infections, with the exception of the first case seen which harboured both *P. vivax* and *P. malariae*.

The infected area on the east bank extended from Grove to Soesdyke, a distance of 11 miles (18 km); in all, there were 37 cases in a total population of 11 155, and the last case was recorded on 24 October 1961. On the west bank, the infected area extended over a distance of 25 miles (40 km); in all, 52 cases were identified in a total population of 13 004, the last case being reported on 20 February 1962.

The distribution of the cases is shown in Table 5 and in Fig. 1.

The majority of cases occurred in August and September 1961; the subsequent decline was related not only to the customary seasonal fall-off in transmission, but also to the introduction of wholesale suppressive treatment, which got under way in October. This treatment, however, was stopped on 15 April 1962 on the east bank and on 31 May 1962 on the west bank.

Suppressive treatment, unless continued systematically and indefinitely, tends to mask infection without curing it: in a small and delimited outbreak, such as the one under study, it is better to allow infections to become clinically active so that they

TABLE 5

DEMERARA ESTUARY: DISTRIBUTION OF MALARIA CASES RECORDED FROM 21.7.61 TO 30.6.62

Locality	Population [a]	No. of houses	No. of cases	No. of infected houses	Date of	
					First case	Last case
East bank:						
Grove	6 006	924	6	5	21. 7.61	12.10.61
Craig, Hope, Friendship, Garden of Eden	2 609	473	9	6	22. 8.61	24.10.61
Brickery, Coverden, Soesdyke	2 496	1 066	5	5	11. 9.61	7.10.61
Wharton Hill	44	11	17	5	14. 8.61	14.10.61
Total	11 155	2 474	37	21	21. 7.61	24.10.61
West bank:						
Canal Polder No. 1	3 240	617	2	2	19.10.61	19.10.61
Canal Polder No. 2	3 186	836	23	19	31. 7.61	4.10.61
Belleview, Sisters, Good Intent	3 232	786	4	4	25. 7.61	16.10.61
Wales Estate	2 611	400	7	6	10. 8.61	26.10.61
Free and Easy, Maria's Lodge	165	39	9	5	4. 9.61	25. 1.62
Vriedenstein, Princess Carolina	570	145	7	7	1. 9.61	20. 2.62
Total	13 004	2 823	52	43	25. 7.61	20. 2.62

[a] The population figures in this table were obtained by direct enumeration in 1961-62 in the course of routine surveillance operations.

may be identified and treated radically. During July 1962, in the second month after the withdrawal of suppressive treatment, four more cases were recorded: two from the same house at Vriedenstein, one from Free and Easy and one from Princess Carolina. These west bank localities total a population of 735, and there is much interchange between settlements. During July, 654 slides were examined (88% of the population), but no further cases of malaria infection have been detected up to the time of writing. Thus, since the beginning of this outbreak in July 1961, 93 cases have been recorded: 92 *P. vivax* infections and 1 *P. vivax* - *P. malariae* infection.

According to reports, the fever attacks were generally severe, but few patients were hospitalized and the majority were seen after the more acute phase had passed; 65% of the affected persons were under 15 years of age.

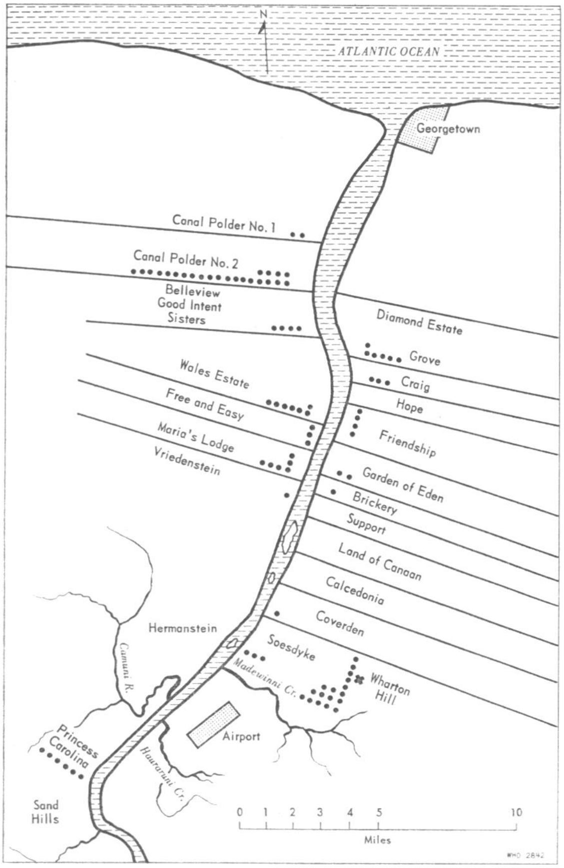
Table 6 summarizes the parasitological findings in a total of 10 254 slides examined: the slides were taken from patients with fever, with a history of recent fever, or just at random.

Origin of primary infection

Within the infected area, the Demerara estuary is about two-thirds of a mile (1 km) in width. Its general direction is from north to south and it is swept by strong, more or less constant breezes from the north-east. The river thus constitutes an effective barrier to anopheline flight and, to some extent, to human traffic, as it can be crossed only by ferries at Georgetown and Grove village. It appears unlikely, therefore, that the outbreaks on the two banks were directly connected; it is more probable that they developed in parallel but independently, through the same mechanism and under similar environmental conditions.

FIG. 1

SKETCH MAP OF DEMERARA RIVER ESTUARY, SHOWING DISTRIBUTION OF THE 89 CASES OF MALARIA RECORDED BETWEEN JULY 1961 AND JUNE 1962 [a]



[a] Each black dot represents a malaria case; dots vertically superimposed on each other indicate that the cases occurred in the same house. Thus, for example, 2 of the 7 cases in Wales Estate and 3 of the 6 cases in Maria's Lodge were in the same house.

The first patient, diagnosed in Diamond Estate hospital on 21 July 1961, had history of fever attacks since the middle of May. Some six weeks before the onset of fever, two visitors from the Aruka river, a known infected area in the North-West District, had been guests of this patient's family for one week.

At Canal Polder No. 2, the information was obtained that some dragline operators had returned to the area in 1960 from the manganese mines on the upper Barima where, as has been stated, numerous cases of malaria occurred in 1950-60.

In a previous section, data have been given on the occurrence of confirmed malaria cases in the far interior since 1950. A small but constant reservoir of infection has evidently existed in the interior ever since the eradication of *A. darlingi* and malaria was achieved on the coast, some 12 to 16 years ago. During the 1958, 1959 and 1960 malaria exacerbations in the interior, which have been described, the influx of parasite carriers to the coastal areas inevitably became greater and more frequent. The closing down of construction operations at the manganese mines in the latter part of 1960, with general retrenchment of workers, has been mentioned. Apart from this unusual occurrence, it is, however, customary for miners and other workers in the remote interior to return to their families on the coast for the Christmas season, which coincides with the heavy winter rains and floods which hamper work in the interior.

It is important to note that the influx of parasite carriers has by no means been limited to the Demerara river estuary; special conditions thus appear to have developed in this restricted area to make transmission of the infection possible.

We have found that the residents of the small settlements, living south of the larger inhabited centres on the estuary—Grove, Wales Estate and Canal Polder No. 2— visit these centres frequently to spend time with relatives. It is evident that the infection smouldered for some months before it was discovered; the first cases, presumably, originated in the more populous centres early in 1960; by 1961 cases had become sufficiently numerous and scattered for active transmission during the May-July season, when the first cases were actually discovered.

Mode of transmission

Between 24 July and 26 October 1961, adult *Anopheles* captures were carried out in 1019 houses throughout the area, before spraying operations were begun: day captures (7 a.m. to 9 a.m.) were made in 837 houses and night captures (7 p.m. to 10 p.m.) in 182. Day captures are the most effective when searching for *A. darlingi*, but give little information on *A. aquasalis* activity. Table 7 summarizes the results of these investigations.

A. darlingi. No evidence of the presence of this dangerous species, our former vector, was collected. It is felt that if it had been involved, it would certainly have been found easily, particularly at Wharton Hill—a small group of 11 houses, surrounded

TABLE 6

DEMERARA ESTUARY: BLOOD SLIDE EXAMINATIONS, JULY 1961 TO JUNE 1962 [a]

Year and month	East bank						West bank						Total no. of slides examined
	With fever		With history of fever		Without fever		With fever		With history of fever		Without fever		
	No. of slides	No. positive	No. of slides	No. positive	No. of slides	No. positive	No. of slides	No. positive	No. of slides	No. positive	No. of slides	No. positive	
1961													
July	29	1 *P.m.* + *P.v.*	59	—	26	—	—	—	—	—	—	—	114
Aug.	111	8 *P.v.*	28	—	120	2 *P.v.*	177	19 *P.v.*	192	3 *P.v.*	1 281	1 *P.v.*	1 909
Sept.	199	18 *P.v.*	32	—	5	1 *P.v.*	323	11 *P.v.*	277	—	1 300	—	2 136
Oct.	188	5 *P.v.*	231	2 *P.v.*	10	—	207	11 *P.v.*	118	—	107	—	861
Nov.	64	—	59	—	36	—	202	2 *P.v.*	44	—	56	—	460
Dec.	59	—	284	—	25	—	113	—	46	1 *P.v.*	89	—	616
1962													
Jan.	172	—	111	—	42	—	264	3 *P.v.*	104	—	220	—	913
Feb.	81	—	36	—	21	—	90	1 *P.v.*	32	—	113	—	373
March	24	—	14	—	11	—	118	—	44	—	72	—	283
April	49	—	7	—	30	—	100	—	39	—	49	—	274
May	248	—	516	—	1 164	—	85	—	33	—	47	—	2 093
June	5	—	1	—	33	—	82	—	65	—	36	—	222
Total	1 229	31 *P.v.* 1 *P.m.* + *P.v.*	1 378	2 *P.v.*	1 522	3 *P.v.*	1 761	47 *P.v.*	994	4 *P.v.*	3 370	1 *P.v.*	10 254
Positive rate	2.6 %		0.14 %		0.19 %		2.6 %		0.40 %		0.02 %		0.87 %

[a] *P.m.* = *P. malariae* infection; *P.v.* = *P. vivax* infection.

by forest—where no less than 17 cases of malaria occurred in a population of only 44 inhabitants.

A. aquasalis. This mosquito was found to be abundant and very active in the houses at Wharton Hill; it was also collected in houses on both banks of the estuary, both by day and by night, more frequently than in any previous survey. This species represented 81% of the total anopheline catch, and practically all specimens collected were engorged. Unfortunately, 286 *Anopheles* collected at Garden of Eden were not identified; however, out of 176 *Anopheles* from this same locality which were identified, 90% were *A. aquasalis*. Accepting this same proportion for the non-classified sample, the average catch per house for this species, on the east bank, was 3.9 per house examined. The entomological survey of the less accessible west bank was started on 25 August, i.e., well after the usual peak season for *A. aquasalis*, and nearly all collections were made by day. These two factors are certainly responsible for the much lower catches.

A. albitarsis and *A. mediopunctatus*. These species were collected in small numbers and most specimens were unfed; it is thus extremely unlikely that either species was involved in transmission.

Dr George J. Burton, Entomologist of the Filariasis Research Unit, carried out the identification of all *Anopheles* collected in September and October and very kindly communicated to us his findings; he also carried out dissections on 510 *A. aquasalis* and 73 *A. albitarsis*. No sporozoite infections were recorded, but two *A. aquasalis*, collected late in October at Garden of Eden, presented oocyst infections. There appears to be little doubt that *A. aquasalis* was the vector responsible for this 1961 malaria recurrence on the Demerara river

TABLE 7

DEMERARA RIVER ESTUARY: HOUSE CAPTURES OF ADULT *ANOPHELES*, JULY-OCTOBER 1961

Locality (date)	No. of houses inspected	Time of inspection [a]	*A. darlingi*	*A. aquasalis*	*A. albitarsis*	*A. medio-punctatus*	Not identified
East bank:							
Grove housing scheme (24.7-12.8.61)	231	Day	0	26	3	0	0
Wharton Hill (19.9-29.10.61)	79	Night	0	85	12	16	0
Friendship (28.9-29.9.61)	19	Night	0	97	20	10	0
Brickery (23.10-26.10.61)	22	Night	0	32	0	0	0
Garden of Eden (23.10-3.11.61)	38	Night	0	165	6	5	286
Soesdyke (24.10-26.10.61)	11	Night	0	0	0	0	0
West bank:							
Stanleytown (25.8.61)	52	Day	0	1	0	0	0
Klein Pouderoyn (27.8.61)	2	Day	0	0	0	0	0
Canal Polder No. 2 (26.8-31.8.61)	208	Day	0	18	15	1	0
(1.9-7.9.61)	209	Day	0	1	5	1	0
(11.9-16.9.61)	135	Day	0	1	2	0	0
(5.10.61)	13	Night	0	0	0	0	0
Total	1 019	Day: 837 Night: 182	0	426	63	33	286

[a] Day (7-9 a.m.); night (7-10 p.m.).

estuary: an entirely new epidemiological and control problem thus emerges in this long-established eradicated area of the Guiana coastal areas.

Ecological changes affecting the ratio of the human to the livestock population

Increase in the human population. Since the eradication of malaria on the Demerara estuary, as elsewhere in the territory, a marked and rapid increase in population has taken place: this is well illustrated by the census returns for 1946 and 1960, for the whole estuary area exclusive of Georgetown city:

	1946	*1960*	*Increase*
East bank population .	20 399	53 848	164%
West bank population .	16 099	24 126	50%

On the east bank, the development of new settlements, buildings and industries has been encouraged by the reconstruction of the road to the airport, 25 miles south of Georgetown.

Housing development. Important housing developments have followed the increase in population; between 1951 and 1961, the whole population on the sugar estates has been re-housed in new residential areas laid out in 0.1-acre (0.04-hectare) lots. On the east bank, 1569 lots have been laid out and occupied; in addition, a number of industrial plants have been constructed. On the west bank, 505 lots have been occupied. These residential and industrial areas have taken over most of the already scanty pasture lands available in the sugar estate areas.

Reduction in the livestock population. Only domestic quadrupeds—cattle, horses, mules, donkeys, sheep, goats and pigs—have been considered. The findings of a census taken by the Department of Agriculture in 1950 have been compared with data collected by the Mosquito Control Service evaluators in the course of systematic visits to every house in the area in 1960, as shown in Table 8.

As can be seen from Table 8, the surveys, which were made separately for all the main localities in the two districts, gave fairly uniform results: in all areas, the number of cattle, horses, mules and donkeys has decreased very substantially in the

TABLE 8

DEMERARA ESTUARY: HUMAN AND LIVESTOCK POPULATION [a]

Locality	Year of survey	Human population	Livestock population						Malaria cases (July 1961 to July 1962)
			Cattle	Horses and mules	Donkeys	Sheep and goats	Pigs	Total	
East bank:									
Diamond Estate to Land of Canaan	1950	6 172	1 119	103	149	374	35	1 780	
	1960	10 960	628	58	65	217	51	1 019	16
Coverden and Soesdyke	1950	1 278	234	0	0	25	12	271	
	1960	1 769	171	0	1	24	212	408	4
Wharton Hill [b]	1950	—	—	—	—	—	—	—	
	1960	44	0	0	0	0	0	0	17
Total	1950	7 450	1 353	103	149	399	47	2 051	
	1960	12 773	799	58	66	241	263	1 427	37
Variation		+71 %	−41 %	−43 %	−55 %	−40 %	+460 %	−30 %	
West bank:									
Canal Polder No. 1	1950	2 194	1 350	3	8	29	87	1 477	
	1960	3 411	456	0	5	77	9	547	2
Canal Polder No. 2	1950	2 177	992	0	18	67	2	1 079	
	1960	4 243	838	3	10	218	27	1 096	23
Belleview [b]	1950	—	—	—	—	—	—	—	
	1960	318	46	0	0	16	6	68	0
Sisters and Good Intent	1950	1 483	90	0	8	36	8	142	
	1960	3 258	71	0	5	39	22	137	4
Wales Estate to Maria's Lodge	1950	1 910	138	82	10	102	5	337	
	1960	2 276	121	46	27	150	31	375	17
Vriedenstein to Princess Carolina [c]	1950	← No record →							
	1960	500	150	0	0	62	167	379	10
Total	1950	7 764	2 570	85	44	234	102	3 035	
	1960	13 506	1 532	49	47	500	95	2 223	56
Variation		+74 %	−41 %	−42 %	+ 7 %	+113 %	− 6 %	−26 %	

[a] Human population figures according to 1946 and 1960 census returns. Livestock population figures according to surveys in 1950 and 1960.

[b] New settlement.

[c] Not computed in total.

10-year period. The number of sheep and goats has increased in a few areas. The number of pigs has remained fairly stationary throughout; only at Coverden and Soesdyke has a large increase taken place, from 12 in 1950 to 212 in 1960. From the point of view of " fixing " *A. aquasalis*, sheep, goats and pigs are poor replacements for the larger animals, as at night flocks are herded into small pens; though their numbers may appear high, therefore, the effect in neutralizing *A. aquasalis* tends to be limited and localized in respect to the larger animals, most of which pass the night in the pastures.

Everywhere, the number of persons per head of livestock has increased substantially. Livestock, moreover, through lack of pastures, increasing urbanization, better housing standards and extending cultivation, are becoming more and more segregated and thus less evenly distributed among the human population. It is of particular interest to note that at Wharton Hill, the isolated, bush-surrounded locality where transmission was most active and 17 persons were infected out of a total population of 44, no livestock whatever exist. On the contrary, in the neighbouring villages of Soesdyke and Coverden, which total a population of 1769, only four cases of malaria were recorded. These are the villages which have gone in for pig rearing; they have a total livestock population of 408, including 212 pigs; the livestock to man ratio is thus 1 : 4.3.

DISCUSSION

In the foregoing sections, many data have had to be presented in order to give a clear idea of the prevalence of the three common coastal *Anopheles* over the past years, and their relation to malaria transmission and to the malaria eradication campaign. It may be helpful here to recapitulate briefly the main points which have been made:

1. Before the introduction of DDT, three *Anopheles* species, all of them known potential malaria vectors, were common and widespread throughout the coastal areas: *A. darlingi* (strictly anthropophilic and endophilic), *A. aquasalis* and *A. albitarsis* (both zoophilic and exophilic).

2. The heavily preponderant role of *A. darlingi* in malaria transmission was established over 25 years ago, but it was felt, given the extremely high incidence of the infection, that *A. aquasalis* and *A. albitarsis* were probably also occasional, or at least accidental, vectors.

3. In the North-West District, on the lower reaches of the many rivers subject to tidal salt water invasion, *A. aquasalis*, in the absence of *A. darlingi*, has long been known to be the sole vector of malaria, which it maintains at a low endemic level.

4. The DDT campaign (1946-50) decisively proved that in the coastal areas and in the interior, *A. darlingi* was the sole and specific vector of malaria. *A. darlingi*, in fact, was speedily eradicated, leaving behind, however, for many months, a huge reservoir of malaria infection. *A. aquasalis* and *A. albitarsis*, both exophilic mosquitos, were not touched by DDT (which was used exclusively as a house spray) and continued to exist in unaltered numbers, but they proved incapable of maintaining malaria transmission, and the disease burned itself out in about three years. On the coast, spraying operations were closed down in 1951, and malaria eradication has been maintained uninterruptedly ever since. In some of the areas first brought under control, like the Demerara river estuary, malaria transmission ceased as far back as 1946. The total population of the eradicated coastal areas at the present day is 555 000.

5. The DDT campaign, which was so successful on the coast and in the more accessible and populous inland districts, failed in the remote interior on account of the very difficult terrain, the widely scattered population and its shifting habits, the rudimentary nature of many of the habitations, which made them unsuitable for spraying, and, finally, the complete lack of antimalarial measures on the Brazilian territory adjoining our border. The population still exposed to malaria infection, at the present day, totals 45 000.

6. Undoubtedly, since 1950, many persons infected with malaria in the interior have reached the coastal areas; some were discovered; many, probably, were not. For more than ten years, no instance of local secondary malaria transmission was recorded. These infected persons from the interior were not a source of undue concern, as in view of the absence of *A. darlingi* and the proven negative roles of the other species, the possibility of secondary malaria transmission appeared remote.

7. In the interior, limited outbreaks of malaria were seen from time to time, notably in 1958-59, on the lower reaches of the many rivers in the North-West District (vector *A. aquasalis*) and in 1959-60, at the manganese mines on the upper Barima and Kaituma rivers (vector *A. darlingi*). Soon after the peak of this last outbreak, some 700 construction workers were withdrawn from this area: 25% returned to Georgetown, 25% to the bauxite mines and 50% to their homes in villages and sugar estates throughout the rural coastal areas. Undoubtedly, a considerable but unknown proportion of these people were malaria parasite carriers.

8. In spite of this wide broadcasting of malaria-infected persons throughout the coastal areas, evidence of secondary malaria transmission has been recorded exclusively on the upper part of the Demerara river estuary, an area with a population of 25 000. In all, 93 cases of *P. vivax* malaria have

been seen; in only one patient was a mixed *P. vivax*-*P. malariae* infection found. The first case was seen on 21 July 1961, the last on 19 July 1962.

9. Systematic searching, carried out both in the early morning and at night, in over 1000 houses yielded no *A. darlingi*. *A. aquasalis*, however, was found to be abundant and very active in the houses, soon after dark and at night; a few engorged specimens were also found resting on the walls of bedrooms during morning inspections. Out of 510 *A. aquasalis* dissected, two were found positive for oocysts.

There can be no doubt that *A. aquasalis* has been responsible for this malaria outbreak, and that it has, in this restricted area of the coast, radically altered its biting habits in respect of man.

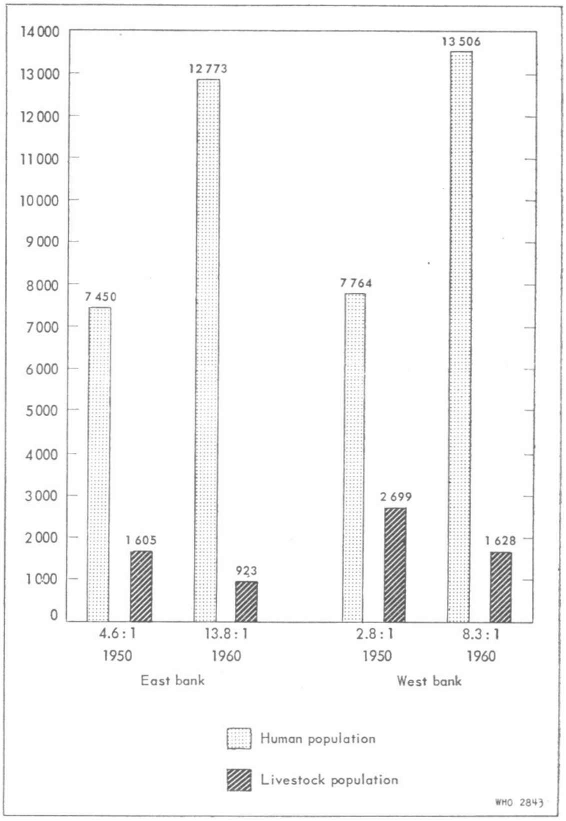
In Trinidad, where *A. aquasalis* is the established malaria vector of the coastal areas, Downs, Shannon & Gillette (1943) observed that the ratio of the human to the livestock population was an important factor influencing the vectorial efficiency of *A. aquasalis*. If the proportion of livestock to man was high, spleen rates were low and *vice versa*.

Shannon (1944) found that one of the major factors contributing to low malarial rates was the strongly zoophilic tendency of this species. Spleen rates varied widely in the villages situated north and north-east of the Caroni-Laventille swamp, a highly productive breeding-ground; *A. aquasalis* densities were everywhere more than ample to maintain a high degree of malaria transmission. During the years 1941 and 1943, the villages of Success and Morvant, both with very few livestock, had spleen rates ranging from 23% to 31% and from 14% to 20% respectively. Curepe, in contrast, had a spleen rate ranging from 0.5% to 0.7%. In this last village, privately owned livestock were abundant; moreover, a large buffalo pen was strategically placed between the village and the main breeding-grounds. In this pen, *A. aquasalis* could be collected by the tens of thousands throughout most of the year. The following data, taken from Shannon (1944), serve as an illustration:

	Village		
	South Barataria	*Morvant*	*Success*
Number of houses . . .	1 452	485	803
Number of people. . . .	8 712	2 390	6 388
Number of equines . . .	96	27	24
Number of bovines . . .	368	11	21
Ratio of animals to man .	1:19	1:63	1:140
Spleen rate (1943) . . .	12.4%	19.8%	31.3%

FIG. 2

HUMAN AND LIVESTOCK POPULATION IN THE DEMERARA RIVER ESTUARY IN 1950 AND IN 1960 [a]



[a] In the course of ten years, the number of persons per head of livestock (cattle, horses, mules and donkeys) has risen from 4.6 to 13.8 on the east bank and from 2.8 to 8.3 on the west bank.

When the figures in the above tabulation are compared with those obtained in British Guiana (see Fig. 2), it can be seen that the number of persons per head of livestock is considerably higher in Trinidad than in British Guiana.

We have ourselves pointed out that the absence of livestock is the probable reason why *A. aquasalis* transmits malaria on the tidal reaches of rivers in the North-West District and on the lower Pomeroon.

Since 1946, the population of British Guiana has increased by 62%. For this, the eradication of malaria has been mainly responsible. Population pressure and improved economic conditions have promoted housing and industrial development and a huge expansion in rice cultivation; most available pasture and fallow lands around villages have been taken up, and the cattle which occupied them have been eliminated or pushed into the hinterland. Mechanization—entirely a post-war development—is replacing an ever-increasing number of horses, mules and donkeys on the roads and of ploughing oxen in the rice-fields. Over the last three years 1500 tractors have been registered.

This trend is general and progressive; on the Demerara river estuary, it has been accelerated by the original deficiency in pasture lands, by the district's proximity to the capital and by the reconstruction of the 25-mile highway to the airport. The population on the east bank has gone up by 71% and that on the west bank by 74% since 1946; on the contrary, the number of livestock (cattle, horses, mules and donkeys) has declined by 42% and 40%, respectively, during the past ten years.

Sheep, goats and pigs are less effective than cattle, horses, etc. in "fixing" large numbers of *Anopheles*, as at night they are herded into small pens, while the larger animals, left out to graze in the pastures around the villages, offer a larger and more widely distributed bait for questing mosquitos.

On the Demerara river estuary the critical point has been reached in the human to livestock ratio, and *A. aquasalis* has had to turn to man in its quest for blood. It is only a matter of time, however, before the same critical point will be reached in other coastal areas; a new and dangerous situation is thus developing.

The outbreak on the Demerara estuary has been successfully controlled by six-monthly DDT spraying, by systematic active and passive surveillance, by thorough chloroquine-primaquine treatment of all cases discovered and by suppressive chemotherapy. This, however, in no way solves our long-term problem. To this end, three procedures suggest themselves:

1. Suppression of infection at its source, by eradicating malaria from the interior. The chloroquinized-salt campaign, now in progress, has this specific object.

2. Strict surveillance, passive and active, for the detection of malaria parasite carriers among persons reaching the coastal areas from infected regions of the interior or from abroad.

3. Rationalized and improved conservation of livestock in "green belts" around villages and settlements, through combined planning by municipalities and village councils with the agricultural, veterinary and public health authorities.

These procedures complement one other. The first is already in actual implementation and, even at this early stage, the outlook appears hopeful. The second requires the continued maintenance of an adequate organization with active and efficient laboratory services; constant vigilance and the active co-operation of all medical practitioners and paramedical personnel are imperative. There is very much room for improvement in this respect. The third procedure really constitutes the "common sense" approach; it aims at conserving and developing, rationally and profitably, a *natural* antimalarial factor which is already in existence and has, in the past, proved active and completely efficient. It requires, however, a carefully-thought-out master plan, backed by appropriate legislation, a strong central direction and the whole-hearted co-operation of the public and of all authorities concerned. Here lie the difficulties.

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The malaria outbreak on the Demerara estuary mobilized all available resources and personnel: particularly valuable were the contributions of Dr F. J. Rutten and Dr K. Liang, of Mr G. R. Davidson of the World Health Organization, and, above all, of Mr S. Ramjattan, Organizer of the Malaria Eradication Campaign in British Guiana.

I wish to thank Dr C. C. Nicholson, Chief Medical Officer, Ministry of Labour, Health and Housing, British Guiana, for his constant backing and assistance, and for permitting the publication of this report.

RÉSUMÉ

L'éradication du paludisme et de son vecteur *Anopheles darlingi* le long de la côte de la Guyane britannique a eu pour conséquence une forte augmentation de la population et de considérables améliorations sociales et économiques. La construction d'habitations et d'installations industrielles, l'expansion de la culture du riz ont accaparé peu à peu les terrains vagues et les prairies aux alentours des villages, refoulant les très nombreux bestiaux qui,

auparavant, y pâturaient. La mécanisation croissante, sur les routes et dans les champs, a privé d'emploi des milliers de chevaux, de mulets, d'ânes et de bœufs. La population humaine a augmenté, celle des animaux a diminué; et l'on assiste à un déséquilibre toujours plus accentué entre les uns et les autres. Dans certains endroits, un niveau critique a été atteint, au-delà duquel *Anopheles aquasalis*, moustique abondant et répandu, zoophile et exophile, s'attaque à l'homme. Dans l'estuaire du Demerara, une épidémie de tierce bénigne a été observée en 1961, dans une localité où la transmission du paludisme avait cessé depuis 16 ans. Dans une population de 25 000 personnes, 93 cas ont été signalés. Aucun *A. darlingi* n'a été trouvé, mais de nombreux *A. aquasalis* ont été surpris, piquant le soir à l'intérieur des maisons et même reposant sur les parois des chambres au matin. Deux spécimens porteurs de sporocytes ont été décelés parmi 510 insectes disséqués. Des changements écologiques dérivant de l'éradication même du paludisme ont ainsi contribué à transformer *A. aquasalis*, auparavant inoffensif, en un vecteur actif et potentiellement dangereux.

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