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MALARIA CONTROL AND ERADICATION IN TAIWAN

Progress Report, May 1952 to June 1957

TAIWAN PROVINCIAL MALARIA RESEARCH INSTITUTE
and
WHO MALARIA TEAM IN TAIWAN *

SYNOPSIS

An intensive programme of residual spraying with DDT carried out over a period of 5 years in Taiwan has reduced malaria morbidity to a very low level. Since 1955, the goal has been complete eradication. Some foci of transmission and/or infection remain, however, and although no resistance problems have been encountered, the principal vector, *A. minimus minimus*, is still widely distributed. An elaborate surveillance organization is now in the process of creation, with the object of detecting and eliminating all residual foci of transmission and preventing the importation of fresh cases. It is hoped to complete eradication in another 3-5 years.

General Features of Taiwan

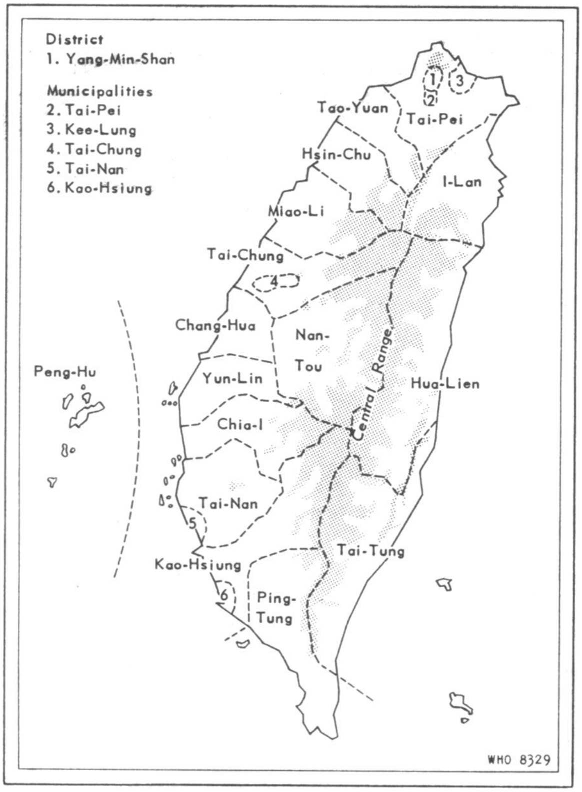
The island of Taiwan—also known as Formosa—is situated 225 miles north of the Philippines and 660 miles south of Japan, and is about 100 miles from the coast of Southern China. It is at present the seat of the Government of the Republic of China, with the national capital at Taipeh.

The greatest dimensions of the island are 240 miles long, from north to south, by 90 miles wide. Together with the adjacent islands, Taiwan has a land surface of nearly 14 000 square miles. Slightly more than two-thirds of this is mountainous (Fig. 1), but there are broad plains in the west, where most of the population is located.

The Tropic of Cancer divides the island into a tropical and a sub-tropical zone, the northern, sub-tropical zone being slightly larger than the southern. The summer season lasts from May to September and is warm to hot and humid; the winter season is usually classed as mild and as lasting from December to February only. The mean temperature is about 73°F (22.2°C)

* The names of the staff members of TAMRI and the WHO Malaria Team who assisted in the preparation of this report will be found in the Annex on page 619.

FIG. 1. TOPOGRAPHY AND POLITICAL DIVISIONS OF TAIWAN



at Taipeh in the north and 75°F (24.4°C) at Kaohsiung in the south. Rainfall may be heavy during the monsoon season, which lasts from November to April in northern Taiwan (north-eastern monsoon) and from June to October in the south (south-western monsoon). Destructive typhoons occasionally sweep the island between June and October, accompanied by heavy rainfall. The average annual rainfall varies from 50 in. on the western plains to nearly 250 in. around some of the northern ports along the face of the mountain ranges.

Three-fifths of the island's arable land is paddy and is intensively cultivated. Rice, sugar-cane, sweet potatoes, beans and ground-nuts are the staple crops, many crops being grown in one year on the same piece of land. Two crops of rice, each taking three months, plus one or two crops of vegetables or tobacco between seasons, are the usual practice. Coal mines, cement plants, sugar refineries, metallurgical works, oil refineries, fertilizer factories, plywood factories and paper mills are being developed, as well as other industries.

The 1956 census showed the population of Taiwan to be 9 310 000, or about 670 persons per square mile. Since the mountainous areas are only sparsely populated, it is obvious that the population density in the plains is very high.

Growth of Malaria Control in Taiwan

Malaria has no doubt been prevalent in Taiwan for centuries. Statistics for the period 1906-1911 show that at that time it ranked first as a cause of death, killing more than 10 000 people annually out of a total population of slightly over 3 000 000. The disease was widespread among the rural population, particularly those living in the foothills and mountains. Generally speaking, malaria has been considered hyperendemic in eastern Taiwan, the northern coal-mine areas, and the western foothills of the central mountain range, and hypoendemic to mesoendemic in the densely populated western plains (see p. 601).

The first attempts at malaria control in Taiwan, based on regular blood examinations and drug treatment of parasite carriers, were made in 1910. During the next 30 years, the use of such methods enabled the infection rate to be kept between 2% and 4%. With the dislocation caused by the war, however, this system broke down in 1942 and severe epidemics swept the island. Parasite surveys conducted in 1946 in northern, central and southern Taiwan revealed infection rates of 20-40% among primary schoolchildren.

In November 1946, the Malaria Section of the National Institute of Health in Nanking, assisted by the Rockefeller Foundation, established a field laboratory at Chaochow, Pingtung, Taiwan, and in April 1948, this was placed under the supervision of the Provincial Health Administration as a Public Health Institute. Its original purpose was to conduct field experiments on malaria control, as well as to serve as a technical research institute for malaria studies. In 1949 the Rockefeller Foundation withdrew its support and the institute became the present Taiwan Provincial Malaria Research Institute (TAMRI), with responsibility for malaria control and planning operations in Taiwan.

Plans for an island-wide malaria control programme were laid in 1951 at a meeting between representatives of the Public Health Administration, TAMRI, the International Co-operation Administration (ICA), the Council for United States Aid (CUSA), the Joint Commission on Rural Reconstruction (JCRR), and WHO. Certain undertakings were given regarding technical planning and administrative supervision, and in October 1951 an agreement was signed between the Chinese Government and WHO for the provision of assistance. The following month a further agreement was signed between TAMRI and JCRR to provide financial aid for the project, which was started in May 1952.

The original four-year plan was aimed simply at reducing the prevalence of the disease to proportions where it would no longer constitute a major public health problem. The results of the initial control operations were so dramatic, however, that total elimination of the disease appeared to be a practical possibility. Late in 1955 it was therefore decided to shift the objective from malaria control to malaria eradication. This involved prolonging island-wide DDT-spraying for a further two years and putting into operation an effective malaria surveillance programme, to be continued until the objective of eradication was achieved.

Administration and Financing of the Project

As already mentioned, the headquarters of the project is the Taiwan Provincial Malaria Research Institute (TAMRI), located in Chaochow, southern Taiwan. Branch laboratories were situated at Taichung, in central Taiwan, until February 1957, and at Chilung, in northern Taiwan, from 1947 to 1954. The project was conducted as a Government responsibility, but the Senior Adviser provided by WHO in accordance with the agreement assumed the technical and operational direction and served as Project Leader. The Regional Director of WHO and the Regional Malaria Adviser provided such technical advice and guidance as were needed. As the work progressed, the responsibility for the technical and operational direction of the project was gradually taken over by the TAMRI staff. The transfer of responsibility was completed in 1955, and thereafter the WHO staff served only in an advisory capacity. As far as possible, project assessment has been supervised by " headquarters ", but responsibility for field operations has been gradually handed over to local units (hsiens and townships).

In the early days of the Taiwan Malaria Institute, members of the Rockefeller Foundation trained a number of locally recruited personnel in modern methods of malaria control. These formed the nucleus of the TAMRI staff and were able to train other staff members and technicians. In addition, fellowships have been awarded for study abroad in public health, environmental sanitation, medical entomology, malariology and other related fields. The Rockefeller Foundation and ICA have each awarded three fellowships for 12 months' study in the USA, and WHO has awarded eight fellowships for periods varying from 6 weeks to 12 months for study in the United Kingdom, Ceylon, Malaya, Thailand, and Japan.

The malaria control project has been financed from three main sources: the Chinese Government, including provincial, hsien, and township administrations; US-aid agencies, including ICA/CUSA and JCRR; and WHO, under the United Nations Expanded Programme of Technical Assistance. The funds from the Chinese Government have been used mainly for salaries, travel, equipment and supplies that could be purchased locally, and all expenditure of a maintenance nature. US-aid funds have been used principally for the purchase of DDT and spray equipment, and for salaries and travel expenses. The salaries and travel expenses of experts provided by WHO have been paid by that organization. The funds supplied by WHO have also been used to purchase technical equipment and literature not available locally.

The Chinese Government and JCRR contributed their funds in NT dollars, ICA/CUSA financial aid was given both in NT dollars and in US dollars, while WHO assistance was provided entirely in US dollars. Owing to annual adjustments in the NT$-US$ exchange rate, it is not easy to obtain an accurate comparison of the total funds made available each year. The most realistic figure is obtained by converting all funds to NT dollars, as done in Table 1. This shows a steady increase in expenditure from year to year.

TABLE 1. SOURCES OF FUNDS AND ANNUAL CONTRIBUTIONS CALCULATED IN NT DOLLARS

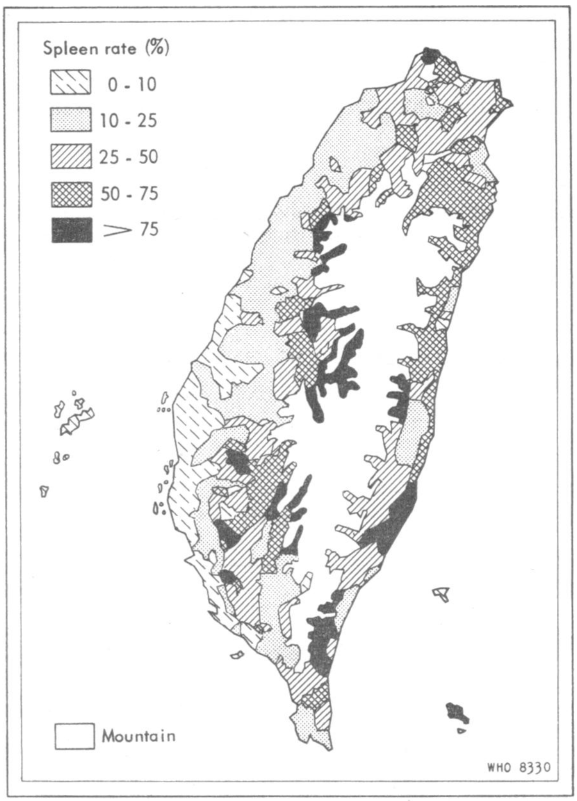
Sources of funds	1952	1953	1954	1956	1956	Totals
Chinese Government	473 170	2 470 660	9 823 770	9 463 370	10 886 500	33 117 470
ICA/CUSA	489 240	4 540 250	8 767 200	9 641 650	11 756 480	35 194 820
JCRR	496 850	505 750	519 750.	0	94 500	1 616 850
WHO	463 500	453 200	350 200	399 080	631 890	2 297 870
Totals	1 922 760	7 969 860	19 460 920	19 504 100	23 369 370	72 227 010

Selection of Areas for Spraying

When the project was started in May 1952, Chishan District of Kaohsiung Hsien, with a population of 37 000, was selected as a pilot area for the initial spraying operations. This area was chosen because it was highly malarious and sufficiently large to permit statistical evaluation of the results, and because it was readily accessible to TAMRI-headquarters, thus facilitating observation and training of personnel. It was also hoped that a number of surrounding townships, with a total population of 21 000, would serve as a control area. In 1953, spraying operations were extended to all parts of Taiwan having a spleen rate of 35% or more, as well as to areas surrounded by townships with spleen rates of more than 35%. Spleen rates were assessed by examining 50 children from a primary school in the most malarious village of each township. During the second half of 1953, the most elaborate survey ever undertaken on Taiwan was carried out.

WHO and TAMRI malariologists visited each of the 847 primary schools on the island and made spleen examinations of samples of 200 children from the junior classes of each school. Any township with a spleen rate of more than 10%, or surrounded by other townships with a spleen rate of more than 10%, was included in the spraying programme for 1954; and

FIG. 2. MALARIA ENDEMICITY IN TAIWAN IN 1953, BEFORE COMMENCING SPRAYING OPERATIONS



any township with a lower spleen rate but with a definite history of a malaria epidemic during the preceding 10 years was also included. The population of the territory covered was nearly 5 500 000. In 1955, the same areas were sprayed again, but in 1956, coincident with the shift from malaria control to malaria eradication, the programme was expanded to include all areas except those definitely proved to be non-malarious. The 1956 campaign gave protection to a population of nearly 7 000 000 people, i.e. the entire population of Taiwan with the exception of those living in the centres of large towns.

The island-wide spleen survey carried out in 1953 (Demos, Ch'enk & Hsieh, 1954; Wu, 1956) showed the following pattern of malaria endemicity in Taiwan (see Fig. 2):

(i) hypoendemic regions (spleen rate below 10%) at altitudes of over 1000 metres (with the exception of a few villages at altitudes of 1000-1300 metres in Nantou Hsien of Central Taiwan), and the municipal centres, southwestern coastal townships, and Penghu;

(ii) mesoendemic regions (spleen rate 10-50%) between the foothill townships and the hypoendemic townships in the lowlands;

(iii) hyperendemic regions (spleen rate over 50%) comprising townships along the foothill areas and lower parts of mountains, as well as Lanyu island in Taitung Hsien.

No real holoendemic area was identified in Taiwan.

The Spraying Programme

Organization

For the spraying operations, the island was divided into four operational regions—central, northern, eastern and southern Taiwan—which were sprayed in rotation at the same time each year. Operations were commenced in central Taiwan in February or March and finished in southern Taiwan in October or November.

At the beginning of each year's spraying period, a special training class was held at the TAMRI headquarters for the 28-35 supervisors who would be the key personnel for the respective hsien and municipality spraying programmes. These men then assisted in regional training courses for supervisors and foremen. Since 1956, each hsien has organized its own classes for supervisors and foremen, who afterwards returned to their respective townships and proceeded to train operators and helpers locally. Field operations were started as soon as the spraymen's training was complete. Each team consisted of a foreman, four spraymen and two helpers, with the necessary equipment and insecticide. While his crew were engaged in spraying, the foreman called on each household and explained the purpose of the programme and the precautions that the householder should observe to ensure the success of the project.

All the townships in a region started spraying on the same day. The teams usually started in the outer, more sparsely populated areas, gradually working towards the centres of townships and villages. The foreman checked the spraying speed and quality of work of each sprayman at least twice a day. He was responsible for inspecting treated houses and giving his " O.K.", for maintenance of the spraying equipment, and for keeping a daily record of DDT consumption, populations covered, number of structures sprayed and time spent.

The township supervisor spent half his time with the squads as inspector, co-ordinator, and public relations man, and the other half on administrative work, combining the reports of the various foremen and making a record of the progress of the work. The hsien supervisor travelled from township to township, helping the township supervisors to solve administrative and technical problems and co-ordinating the work of the hsien. He was able to keep the hsien health officer constantly informed of the problems encountered and of the progress of the work. On completion of the programme, he collected and analysed all the field data, assisted by his TAMRI counterpart. Finally, the TAMRI personnel acted both as instructors and supervisors, assisting the hsien supervisors wherever necessary. The rest of their time was spent in repairing sprayers, statistical analysis of field data, research, and incidental engineering duties at headquarters.

Technical details

The material used throughout most of the campaign was 75% water-dispersible DDT powder, applied once a year at the rate of 2 g per m^2. Since 1956, a mixture of DDT and BHC has been used which deposited 17 mg of gamma-BHC and 2 g of technical DDT on each square metre of surface treated. At first, all DDT was imported from the United States through ICA, but in 1953 a local plant started manufacturing DDT. The product was tested by Dalare Associates, Philadelphia, USA, and found to be in conformity with WHO specifications. The plant supplied one third of the insecticide used in 1953, one half in 1954, four fifths in 1955, and the whole of the requirements in 1956. Locally manufactured sprayers, both of the compression and the multi-outlet type (Echavez, 1956), also became available in 1954. They were manufactured by the Ta-cheng Iron Works in Taipeh, and before being put into operation, they were tested and approved by TAMRI engineers.

In 1953, when the first island-wide application of DDT was undertaken, the public welcomed the spraying squads, but it was the dramatic disappearance of bedbugs, houseflies, fleas and other domestic pest insects, rather than the reduction in malaria, that mainly secured such enthusiastic support. When the efficacy of DDT against these pests began to wane (see p. 610), so did the popularity of the spraying campaign. In 1955, many people began to refuse spraying, the main reasons given being as follows:

(*a*) inefficacy of DDT against pest insects;

(*b*) DDT caused death of cats;

(*c*) stains on walls and furniture caused by spraying.

Many people were also unwilling to take the trouble to move their household effects to enable spraying to be carried out; but perhaps the decrease in malaria was itself the most important reason for the loss of enthusiasm. To combat this situation, it was decided to use the DDT-BHC mixture in the 1956 campaign. This produced an appreciable knock-down of domestic insects, and complaints about the inefficacy of spraying were much less frequent. Even so, nearly 5% of the population in the areas scheduled to be sprayed in 1956 refused spraying. Fortunately, most of the refusals were in towns where malaria was not a serious problem.

In 1955, difficulties were also experienced because local authorities became reluctant to approve the allocation of adequate funds. They could not understand why the few remaining cases of malaria should cost as much as the one million cases at the beginning of the project, and instead of becoming enthusiastic supporters of total eradication, they placed their faith in minimum control measures. Through the efforts of the local health officers and headquarters personnel, however, the programme has been kept in operation.

Malariometric Assessment of the Project

The results were assessed mainly on the basis of spleen and parasite rates in primary school children, infant parasite rates, and morbidity in the general population. Malaria infection rates are known to vary considerably from one locality to another, even within a small area. Standardization of the methods used in sampling and the techniques of examination are therefore essential. The following procedures were adopted:

1. The island-wide parasite surveys among pre-school children were conducted simultaneously on the same day—17 December—each year.

2. The spleen surveys among primary school children were made in the most malarious areas of each township in each hsien and each municipality section.

3. The parasite surveys among infants were conducted in children one year of age.

4. Morbidity studies were carried out in all the areas which formerly had a high malaria infection rate.

Surveys were carried out by the technicians of TAMRI and by 150 local malaria technicians. Both thick and thin blood smears were usually prepared on the same slide. More than 100 microscope fields were examined in each thick smear. In the early stages of the project, the examination could be completed in about three minutes, but as the parasite rate fell, detection of plasmodia became more difficult, and since 1956 a much longer time—up to 15 minutes—has been necessary. The discovery of even a single gametocyte may, of course, indicate a possible focus of infection. For spleen surveys, the modification of Hackett's technique devised by Chen, Wu and Hsieh (1954) at TAMRI was found to provide a sensitive measure of minor splenomegaly.

In the morbidity studies, house-to-house surveys were made in the malarious areas, and all fever cases that had occurred during the preceding six months were investigated. From a list of residents supplied by the township office, a report form was prepared on which to record locality, population, number of persons per household, number contacted, and number with fever. Each fever case was classified according to whether fever was present at the time of the visit, during the preceding week, or during the preceding 6 months.

Two separate assessments were made, one for the Chishan pilot project and one for Taiwan as a whole. Residual house-spraying once a year with DDT at a dosage of 2 g per m^2 has completely changed the malaria picture in the Chishan district in the short space of four years. Two rounds of DDT spraying practically stopped transmission and no new malaria infections in infants have been detected since November 1953. Spleen rates in primary school children have fallen from 52.28% in 1952 to 6.88% in 1956 and parasite rates have been reduced from 23.04% to 0.13% (Table 2).

TABLE 2. SPLEEN AND PARASITE RATES IN CHILDREN AGED 2-14 YEARS IN THE CHISHAN DISTRICT OF TAIWAN, 1952-1956

Survey dates	Spleen examination			Blood smear	
	Number examined	Spleen rate	Average enlarged spleen	Number examined	Parasite rate
June 1952	1 687	52.28	2.24	1 953	23.04
June 1953	1 705	24.22	1.87	1 705	5.10
June 1954	2 071	18.88	1.16	2 275	0.13
May 1955	2 235	11.45	1.37	2 235	0.40
June 1956	2 292	6.88	1.17	2 292	0.13

DDT spraying was carried out each year in August and September.

However, for the past two years parasite rates have been maintained at almost the same level and as late as June 1956, 12 positive cases were found in the Chishan district. There is evidence that transmission still continues at places where careful and extensive spraying has been done for several years, so that eradication does not yet seem to be in sight. The idea of using the townships around Chishan as a control area had to be abandoned in 1953, as the dramatic effectiveness of the spraying operations led to demands for equal treatment.

TABLE 3. RESULTS OF ISLAND-WIDE PARASITE SURVEYS IN PRE-SCHOOL CHILDREN IN TAIWAN, 1951-1956

Year	Number of townships included	Number of children examined	Number of positive cases					Parasite rates %
			P. vivax	P. falc.	P. malar.	Mixed	Totals	
1951	139	13 885	375	669	84	70	1 198	8.63
1952	143	14 213	532	778	34	41	1 385	9.74
1953	145	14 419	245	337	46	32	660	4.58
1954	147	14 614	90	68	10	5	173	1.18
1955	148	14 759	12	9	5	4	30	0.20
1956	150	14 825	0	2	0	0	2	0.01

The surveys were conducted simultaneously throughout the island on December 17 each year. Spraying campaigns were carried out in 1953, 1954, 1955 and 1956.

The results of the island-wide surveys are shown in Tables 3 & 4 and in Fig. 2 & 3. Following the first spraying operations in 1953, there was a sharp drop in the parasite rates and a steady increase in the number of townships in which no positive cases were found. Between December 1954 and May 1955, an island-wide survey of infant parasite rates was conducted in Taiwan to determine whether new malaria infections were occurring after two rounds of DDT spraying. With the assistance of the township health stations, blood smears were collected from all babies under 12 months of age living in the most malarious parts of each township on the island. Altogether 63 460 smears were collected by 368 health

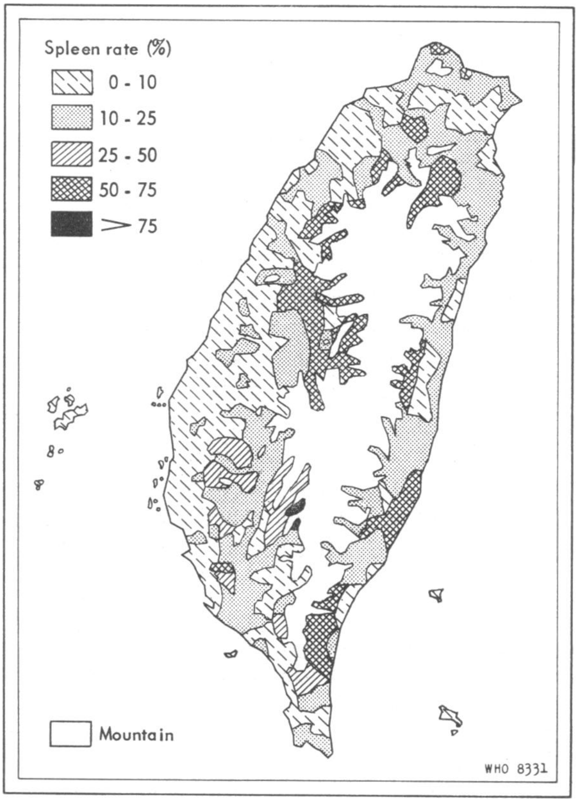
TABLE 4. RESULTS OF ISLAND-WIDE PARASITE SURVEYS IN TAIWAN, 1951-1956, SHOWING TOWNSHIPS GROUPED BY PARASITE RATES

Year	Number of townships included	Number of townships with parasite rates of				
		15% or more	10-15%	5-10%	0-5%	0%
1951	139	23	13	33	52	18
1952	143	38	13	20	48	24
1953	145	16	3	15	46	65
1954	147	2	3	6	45	91
1955	148	0	1	0	12	135
1956	150	0	0	0	2	148

The surveys were conducted simultaneously throughout the island on December 17 each year.

stations. The slides were examined by TAMRI technicians and 8 were found to have malaria parasites (5 *Plasmodium falciparum* and 3 *P. vivax*). The total number of births per year in Taiwan is estimated to be 350 000. It will be noted from Table 3 that whereas *P. falciparum* was the parasite most frequently found in the early surveys, *P. vivax* became the dominant species in 1954 and 1955.

FIG. 3. MALARIA ENDEMICITY IN TAIWAN IN 1955, AFTER TWO ROUNDS OF DDT SPRAYING



The first island-wide spleen survey conducted in 1953 has already been discussed (p. 599). During the second half of 1955, a second island-wide survey was carried out, limited this time to the school in each township that had shown the highest spleen rate in the first survey. The maps shown in Fig. 2 & 3 are based only on the spleen rates of schools sampled in both surveys, and are therefore strictly comparable. The average spleen rate for the island in 1953 was 25.52%, with an average enlarged spleen of 1.66; the corresponding figures for 1955 are 11.71% and 1.29 respectively.

The house-to-house fever surveys have shown a tremendous reduction in malaria morbidity. In 1951, the total number of malaria cases throughout the island was estimated to be 1 200 000; the number of confirmed cases in 1956 was 492.

Malaria Outbreaks during the Campaign

Localized outbreaks of malaria have occurred while the spraying operations were in progress. These have been attributed to immigration, extension of irrigation systems, and to dislocation caused by earthquakes, floods, typhoons, etc.

A severe outbreak in Kaoshu township of Pingtung Hsien (South Taiwan) was discovered in October 1953 by a TAMRI malariologist making a general survey in South Taiwan. The previous survey in May 1952 had shown a relatively low spleen rate of 10.19%. The township had not been included in the 1953 programme but was due for spraying again in 1954. In 5 of the township's 18 villages, the new survey revealed spleen rates ranging from 48-68%. In the remaining 13 villages, the rates ranged from 9-25%. There had been a sharp rise in the number of fever cases, and a house-to-house survey gave a morbidity rate of 63% in a sample of about 5000 persons.

The vector mosquito was found to be *A. minimus minimus*, large numbers of which were caught in the affected villages. Newly constructed irrigation systems, heavy rainfalls the previous autumn, and the conversion of sugar-cane fields to rice fields were believed to be responsible for the enormous increase in the population of *A. minimus minimus*. The presence of a reservoir of infection, together with a low communal immunity, had enabled the epidemic to flare up rapidly. The epidemic was rapidly brought under control by instituting an emergency programme of residual spraying with DDT and drug treatment with proguanil and mepacrine. Infant parasite rates were brought down from 25% in October 1953 to 0.88% in December 1953. Had a more efficient reporting system been organized, appropriate measures could have been taken at an earlier stage and the epidemic prevented from reaching such proportions.

The present malaria situation in Taiwan as a whole is epidemiologically similar to that in Kaoshu township before the above outbreak occurred. The disease has not been finally eradicated and populations of *A. minimus minimus* are still present. It is quite possible therefore for sudden epidemics to occur.

Government migration projects have also been responsible for a number of outbreaks in aboriginal townships in the island. The most recent was in the Yani township in the mountains of Kaohsiung Hsien. Investigation showed that it was confined to a group of migrants of low communal immunity who had moved to Yani from a high mountain village. Soon after this village had been sprayed for the first time in August-September 1954, the group moved down to Yani township where they were housed in newly-built, unsprayed houses. Annual spraying operations in this area did not begin until July 1955, after the epidemic had taken place.

Entomological Studies

While the spraying operations have been in progress, a team of entomologists and technicians has been studying the distribution of the anopheline vectors, their taxonomy, density and bionomics. The resistance of the vectors and of other insects to DDT has also been studied.

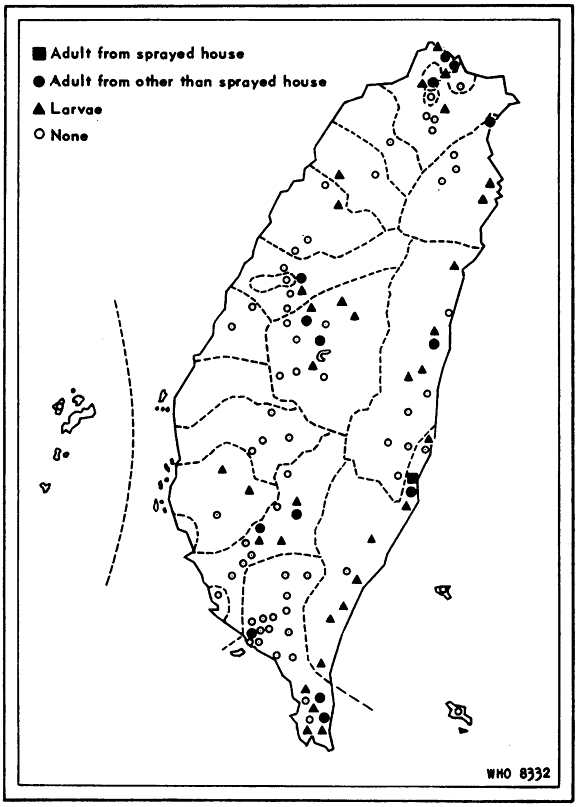
Up to the present time, the following sixteen species of *Anopheles* have been identified in Taiwan (Chang & Huang, 1954; Chow, 1949; Colless, 1956):

A. aitkeni bengalensis
A. annularis
A. barbumbrosus
A. fluviatilis
A. gigas baileyi
A. hyrcanus sinensis
A. insulaeflorum
A. jeyporiensis candidiensis
A. leucosphyrus balabacensis
A. lindesayi
A. ludlowi
A. maculatus
A. minimus minimus
A. splendidus
A. subpictus indefinitus
A. tessellatus

Earlier work had indicated that *A. minimus minimus* and *A. hyrcanus sinensis* were probably the chief vectors of malaria (Anazawa, 1931; Chow, Watson & Chang, 1950; Morishita & Katagai, 1933; Omori, 1942). In 1951, however, Chow, Liang and Pletsch (1951) dissected 965 specimens of *A. hyr. sinensis* collected from human dwellings in southern Taiwan and found only one immature gut infection. They concluded that the rôle of *A. hyr. sinensis* in malaria transmission needed further examination. One of the eight positive slides found in the 1947-1949 studies (Chow, Watson & Chang, 1950) had been retained at TAMRI. This was re-examined and it was found that what had previously been identified as malaria sporozoites were actually crithidial flagellates. It was therefore concluded that *A. hyr. sinensis* does not play an important part in malaria transmission and that *A. minimus minimus* is the chief vector in Taiwan.

A. minimus minimus is one of the commonest species of *Anopheles* in Taiwan. It is widely distributed throughout the island (Fig. 4) and is particularly abundant in foothill regions and in areas where irrigation systems are well developed. Its typical breeding place is in slow-running streams with grassy edges, and it especially favours valley situations where small streams persist throughout the year. Larvae have also been found in temporary water-bodies, such as rock pools, water holes along highways, small pools in fallow fields, and at the edges of rice-fields.

FIG. 4. DISTRIBUTION OF A. MINIMUS MINIMUS IN TAIWAN, MAY 1955-JUNE 1957



As reported by Morishita et al. in 1933, *A. minimus minimus* is highly anthropophilic, being commonly found in human dwellings during the day-time. Of 25 656 specimens of *Anopheles* collected between April 1952 and June 1954 from 1118 houses scattered over the island, nearly 80% were *A. minimus minimus* and 16% were *A. hyr. sinensis* (Pletsch, Tseng & Ch'en, 1956). On the other hand, *A. hyr. sinensis* predominated in a number of cowsheds. In houses, the favourite resting place of *A. minimus minimus* is the bedroom (Tseng & Ch'en, 1956). Nearly a quarter of all the specimens caught were found underneath beds. Other preferred resting places were underneath furniture, in roofs, and on walls within one metre of the floor.

Effects of spraying

A number of houses were set aside as routine collecting stations and examined once or twice during the project period. Routine collections were also made from certain unsprayed stables and from larval breeding places. The sites of the collecting stations were so chosen that they provided an island-wide picture of the entomological situation. The effectiveness of insecticide spraying was assessed biologically by a modification of the method described by Simmons et al., and the method of Busvine and Nash was used to test insecticide susceptibility.

In general, *A. minimus minimus* practically disappeared from all areas contiguous to buildings sprayed with DDT, and the malaria indices dropped sharply. Residual foci of malaria transmission are still present in some formerly malarious areas in the foot-hills and mountainous regions, where a low density of *A. minimus minimus* has been maintained. Investigations have shown that colonies of *A. minimus minimus* can survive in remote jungle areas without access to human blood.

None of the studies has revealed any evidence of behaviouristic or physiological resistance developing in *A. minimus minimus* (Liu, 1958). In some of the residual foci, the persistance of transmission has been suspected to be due to anopheline species other than *A. minimus minimus*. Particular attention has been directed to *A. maculatus* which has been found in large numbers in such areas. Although the ability of this mosquito to act as a malaria vector has not yet been established, its possible importance cannot be overlooked. Further studies on the vector problem are at present in hand at TAMRI.

Other insects

Bedbugs. Before DDT spraying was commenced, the bedbug *Cimex hemipterus* was very prevalent in Taiwan, especially in the aboriginal townships. In some villages the infestation rate ranged from around 20% to almost 100% of the houses surveyed (Ch'en, Lien & Tseng, 1956). During the first two years of DDT spraying, the insect was very effectively controlled, but in the third year bedbugs began to reappear in houses in southern and eastern Taiwan (Ch'en, Tseng & Pletsch, 1956). Laboratory and field studies confirmed that insecticide resistance had developed. So far, this phenomenon has not been observed in northern and central Taiwan, which have remained practically free from bedbugs.

Headlice. Observations on control of headlice are confined to Lanyu (Orchid Island). Before spraying started in June 1953, 76% of the 1400 inhabitants were found to be infested with headlice. The affected persons were instructed to wash their hair with DDT suspension or with the water which had been used to clean the sprayers at the end of the day. The rate dropped to 19% in December 1953 and to 1.8% in 1954. By April 1956, not a single positive case was found among 508 persons examined.

Cockroaches. The cockroach population was reduced considerably by treating the insides of food cabinets when houses were sprayed. In Chinshui township (central Taiwan) the infestation rate, as estimated by visual inspection, was reduced from 17% to 4% by one application of spray (Ch'en, Lien & Tseng, 1956).

Fleas. Limited observations indicate that fleas on beds were usually well controlled by house spraying, but that fleas on dogs, cats and other animals were not much affected. It was reported that fleas were still prevalent in mountain villages after spraying (Ch'en, Lien & Tseng, 1956).

Culicine mosquitos. From the limited observations made, it would seem that culicine mosquitos disappear from houses after the initial spraying, but return. In the case of *Culex fatigans*, the commonest pest mosquito in Taiwan, effective control lasted for two months after the initial application of DDT but for only a few days after subsequent treatments. Laboratory tests indicated that *C. fatigans* larvae reared from eggs collected from an area sprayed four times were 71 times more tolerant to DDT than a laboratory strain from an unsprayed area (Liu, 1958). On the other hand, *Aëdes aegypti*, a species found only in southern Taiwan, was still sensitive to DDT after several sprayings.

Houseflies. Like *C. fatigans*, houseflies soon developed resistance to DDT. Biological tests indicated that they were more sensitive to DDT than *C. fatigans*, but in practice they appeared to be less susceptible. This may have been due to the fact that they had less chance of contact with the sprayed surface.

Silkworms. Laboratory tests showed that silkworms became intoxicated after exposure to DDT and usually died in 30-72 hours, with signs of marked dehydration. Field investigations revealed, however, that the severe losses reported by farmers during the early days of DDT spraying were exaggerated, and that the losses were apparently due in part to other causes. The timing of the spray application in relation to the rearing period was found to be very important. Silkworms brought into rooms 1-5 hours after spraying showed a mortality of 67-71%; those brought into rooms 15-30 days after spraying showed a mortality of only 1-5%. The cocoon production of the surviving larvae was not affected.

Fish seedlings. Collection of " milk-fish seedlings " (*Chanos chanos*) is very common during the summer months along the sea-coasts of eastern and southern Taiwan. Frequent losses of fish seedlings reported to TAMRI staff were found to be due to careless handling of catching equipment which had been contaminated with DDT. Appropriate instructions were issued to spray squads and fish seedling collectors in order to avoid further unnecessary losses.

Residual Foci of Malaria Infection

Mainly as the result of the island-wide campaigns of residual spraying with DDT conducted from May 1952 to June 1957, a large part of Taiwan is now free from malaria. Surveys started in October 1955 have shown, however, that malaria transmission, or residual infection without evidence of transmission, is still present in 84 townships in which spraying has been carried out (Table 5). These townships are situated in the formerly malarious areas, along the foothills of the Central Mountain Range and the Taitung Mountain Range. The malaria cases are generally along the upper reaches of the rivers.

TABLE 5. NUMBER OF TOWNSHIPS WITH MALARIA TRANSMISSION OR RESIDUAL INFECTION, OCTOBER 1955-JUNE 1957

Criterion	Number of townships	Population	Type of situation
At least one case of plasmodial infection (all species) among children born after the initial house spraying	20	288 300	Post-operational transmission
At least one case of *P. falciparum* infection among pre-operational age-groups	30	454 800	Presumably post-operational transmission
At least one indigenous plasmodial infection with *P. vivax* or *P. malariae*	34	541 100	Residual infection

The majority of the inhabitants in the transmission foci are either migrant or temporary residents, such as woodcutters, fishermen, or labourers on banana plantations. They return periodically to their home towns to spend a few weeks with their relatives and friends. During the harvest and planting seasons, a considerable number of outside helpers are brought in. The houses of these workers are below the usual standard, and are built of canes, wattles or miscanthus (a local bushlike plant), with low, thatched roofs and no chimneys. Cooking-fires are built inside the houses, so that the inside surfaces become heavily sooted. Tests have shown that the soot definitely reduces the efficacy of the insecticide. Many of the new malaria cases are found in unsprayed houses or huts which were erected after the annual spraying or were ignored by the spraying squads because of relative inaccessibility.

All the evidence seems to support the view that *A. minimus minimus* is the chief vector of malaria in Taiwan, but it is not known whether it is the only vector (cf. p. 608). Resistance to DDT has not been detected in this mosquito, and a single application of the insecticide is followed by its disappearance from houses. This does not mean, however, that it has been eradicated from all parts of a DDT-sprayed area. In Anso village of Tajen township, Taitung Hsien, no adult mosquitos were collected from sprayed houses, but seven specimens were found in unsprayed woodcutters' huts in the area. Moreover, it has been shown that colonies can be maintained without human association.

Whether a negligible population of *A. minimus minimus* can maintain malaria transmission has not yet been proved, even where larval breeding has been demonstrated. In some focal areas, neither adults nor larvae of this species have been collected at certain seasons, but large populations of *A. maculatus*, *A. hyrcanus sinensis*, and other anophelines are present. Whether these can also act as vectors is at present under study by TAMRI's entomological section, but the number of specimens that have been dissected so far is too small to allow definite conclusions to be drawn. It will be necessary to make a continuous study of all anophelines found in any active or newly discovered foci until the vector or vectors have been definitely identified.

The measures that have been adopted in areas where residual foci have been discovered consist of emergency spraying of unsprayed or improperly sprayed houses and mass treatment of all the inhabitants in the area with antimalarial drugs. The two drugs most readily available were amodiaquine and chloroquine. As a rule, a single dose of one of these two drugs was given, the dosage being 10 mg of amodiaquine or 12 mg of chloroquine per kg of bodyweight. Although this scheme has not proved entirely satisfactory, it has caused a marked reduction in plasmodial infection. It is hoped that in the future the use of primaquine, given regularly by full-time surveillance technicians, will provide better results.

Surveillance Measures

A surveillance scheme is introduced in a malaria eradication campaign after the main spraying programme has succeeded in interrupting transmission and the malaria infection rate has been reduced to a low level. The primary objectives of such a scheme are the detection and immediate elimination of remaining foci of transmission, and the detection and treatment of parasite carriers with long-standing infection. Specially trained surveillance teams make house-to-house visits in potentially malarious areas and institute enquiries in hospitals, outpatient departments of official and private clinics, and other medical institutions.

As it was not possible for TAMRI to employ sufficient additional personnel for surveillance work, arrangements were made with township health stations to release a number of health technicians and sanitary inspectors from other public health duties for 10 days each month to undertake malaria surveillance (Ch'en & Liang, 1956). Only the most malarious area in each township—representing a population of about 5000-6000—was visited by the teams. During the house-to-house visits, blood smears were taken from infants and children born after the initial application of DDT, as well as from fever cases in other age-groups. Particular emphasis was placed on the examination of infants and " post-operational children ", as any positive cases found in this age-group are highly indicative of new transmission. *P. falciparum* infections were also considered important evidence of recent transmission, as this parasite is believed to be the most short-lived of human plasmodia. A summary of the results of the blood surveys carried out by township surveillance units up to June 1957 is given in Table 6.

TABLE 6. RESULTS OF BLOOD SURVEYS CARRIED OUT BY TOWNSHIP SURVEILLANCE UNITS, DECEMBER 1954 - JUNE 1957

Year	Infants and post-operational children			Fever cases					
				Children			Adults		
	Number examined	Positive cases		Number examined	Positive cases		Number examined	Positive cases	
		Number	%		Number	%		Number	%
1954 [1]	1 368	3	0.22	851	7	0.82	285	26	9.13
1955	22 314	13	0.06	8 660	67	0.77	5 432	204	3.76
1956	38 737	3	0.008	5 979	6	0.10	10 785	112	1.04
1957 [2]	16 199	0	0	2 705	0	0	4 216	11	0.26

[1] December only
[2] January-June only

It will be noted that the great majority of parasite carriers were found among adult fever cases. The percentage of malaria infections confirmed in children with fever was low even in December 1954, when the second round of island-wide spraying had only just been completed. Since December 1954, only 19 positive cases have been found among 77 250 infants and post-operational children examined. Steadily diminishing transmission has also resulted in a progressive decrease in parasite rates in other age-groups.

To supplement these active surveillance measures, attempts have also been made to secure the co-operation of doctors, whether in government service or in private practice, in reporting all clinical cases of malaria that come to their notice. Malaria was made a notifiable disease in July 1955, and doctors were requested to send blood smears from all suspected cases to the nearest surveillance unit or health station, or direct to TAMRI for confirmation. They were expected to begin treatment of suspected cases with antimalarial drugs immediately, the cost of the drugs being reimbursed by the local health station. All cases confirmed by microscopic examination were investigated by the local health services. Unfortunately, the response to this scheme so far has not been very encouraging. In May 1956, the detailed procedure of malaria case reporting and treatment was published in the Provincial Gazette, and since then a somewhat larger number of reports has been received. Between May 1956 and June 1957, a total of 280 microscopically confirmed cases of malaria were reported through this channel.

The main reason for the lack of co-operation is that the doctors do not realize the importance of the role they play in the surveillance phase of a malaria eradication campaign. The need for their help should be continually impressed on them, and they should be kept informed of the changing malaria picture in Taiwan, particularly with regard to residual foci of transmission.

Valuable information on malaria morbidity can also be obtained from the periodic returns of the army medical services, a source not yet adequately exploited in Taiwan. A request for notification of malaria cases has also been addressed to the medical services of government departments concerned with certain special population groups, such as temporary labour forces working on various projects, woodcutters, roadworkers, and miners. Such groups of workers are often employed in areas where malaria is still active.

Mobile malaria detection teams

For the purposes of the surveillance programme, Taiwan had been divided into three regions: (A) the former hyperendemic area, plus a part of the former mesoendemic area along the foothills; (B) the former mesoendemic portion of the western plains; (C) the coastal portion of the former mesoendemic area, plus all the hypoendemic area. It was felt that in region A especially, where malaria was formerly hyperendemic, active searching for malaria cases by township surveillance technicians working 10 days a month was hardly adequate. In October 1956, 10 Malaria Detection Service teams were organized, to operate mostly in region A. Unlike other surveillance services, these teams were mobile, moving from one township to another making house-to-house surveys. Each team was composed of 2 TAMRI technicians and 3 local health personnel.

The work of the Mobile Detection Service teams started in October 1956 in northern Taiwan. The villages to be visited had been chosen in advance by TAMRI malariologists, who frequently paid a visit to the area concerned before making an actual decision. The total area to be covered had an estimated population of 878 000 persons, living in what were formerly the most malarious villages on the island. During the period October 1956 to June 1957, more than 480 000 people had actually been visited by the teams and a total of 154 536 blood smears had been collected. Microscopic examination had been completed on 121 627 smears, and 86 were found to have malaria parasites. Fourteen of these cases were detected among post-operative children and 72 among other age-groups, including 25 cases of *P. falciparum* infection. The total number of post-operative children examined was 45 290, and of the 14 positive cases found, 12 had fever at the time of the visit. It is therefore doubtful whether a complete survey of all infants and post-operative children is worth while; considerable time and energy would have been saved if the survey had been limited to fever cases.

With the personnel and resources at present available, the Mobile Detection Service teams can only make a once-a-year coverage of the area to be surveyed. This still does not provide an adequate surveillance service. What is really required is a programme of regular monthly visits to all malarious villages. This is also one of the recommendations made by the WHO Malaria Advisory team, headed by Dr M. E. Farinaud, which assisted in the assessment of the malaria eradication project in January-May 1957. A more adequate surveillance programme, which will require additional personnel and funds, has now been proposed, and is described below.

Future Plans for Malaria Eradication in Taiwan

The present low malaria endemicity in Taiwan constitutes an epidemic potential. If all control and surveillance measures were removed now, it might take only a year or so before major outbreaks occurred again. To attain the final goal of complete eradication, a sound surveillance organization must be built up. This means that adequate financial resources must be available for employing sufficient full-time personnel for as long as needed; it is estimated that under a full-time malaria surveillance scheme, a period of at least 3-5 years will be necessary to eradicate malaria completely from Taiwan. On the other hand, if reliance were placed only on control measures, very considerable sums of money would have to be spent annually. Since May 1952, more than 70 million NT dollars have been spent on malaria control and eradication.

The accepted aim now is to discontinue residual spraying as soon as possible after malaria transmission has been interrupted. Owing to the delay in introducing a sufficiently comprehensive surveillance system in Taiwan, DDT spraying has had to be continued in order to prevent a resurgence of transmission, especially in areas that were formerly hyperendemic. By the end of 1957, DDT house spraying will have been carried out five times in these areas, three times in the areas that were formerly mesoendemic, and once in those that were hypoendemic. During 1956, a population of 6 800 000, living for the most part in the malarious rural areas of Taiwan, was directly protected by residual spraying, the largest annual coverage ever achieved. Residual spraying was then stopped in most of these areas, and in 1957, spraying was confined to certain formerly hyperendemic areas in the mountains and foothills, with a total population of 1 600 000.

In the light of epidemiological and entomological information at present available, it is expected that areas with a population of 400 000 will have to be included in the 1958 spraying programme. The following areas will be sprayed:

1. All residual foci of malaria infection discovered during the past two years.

2. Formerly hyperendemic areas in which breeding of *A. minimus minimus* persists and transmission of malaria is suspected.

3. New settlements within formerly hyperendemic regions, such as temporary villages for woodcutters, labour camps, and settlements for various construction projects.

It is expected that after 1958 spraying will be carried out only on a limited scale as an emergency measure. As the foci of transmission become progressively rarer, it will become more economical and effective to treat the occasional case of malaria with antimalarial drugs.

The surveillance programme

The surveillance programme as at present envisaged will include the following measures:

1. *Detection of persistent highly endemic areas.* For this purpose it is planned to make a fresh survey of all the formerly highly endemic areas. The principal method used will be spleen palpation of children of primary school age, particularly those who come from sparsely populated, hilly areas where breeding of *A. minimus minimus* has continued. It is expected that a team of two or three malariologists, together with the same number of blood technicians, will be able to make a complete tour of all suspected areas in a minimum period of 2 months.

2. *Detection of residual cases of infection or transmission.* This part of the programme will be carried out both by full-time and by part-time surveillance technicians. The full-time technicians will operate in townships where some malaria foci are still found. It is estimated that 300 000 people a month will have to be examined and that about 100 technicians will be needed for this purpose. The part-time technicians will be assigned to formerly malarious areas in which malaria foci are absent.

3. *Epidemiological investigation of transmission foci.* Between 20 and 25 persons qualified in parasitology and entomology will be required to make the necessary investigations.

4. *Studies on the development of resistance in malaria vectors. A. minimus minimus* is still highly susceptible, both to DDT and to gamma-BHC. A limited programme of residual spraying with the DDT-BHC mixture will be carried out in 1958. A comparative assessment of susceptibility will be made in the areas sprayed and in areas where spraying has been discontinued.

4. *Search for malaria vectors other than A. minimus minimus.* Studies will be continued at Nanhsi (Tainan Hsien) and at Tajen (Taitung Hsien).

The mosquitos will be collected from houses, preferably by window traps, during the night and in the early morning ; and early morning collections will also be made from outside resting places near houses where gametocyte carriers are likely to be found.

5. *Elimination of residual foci.* Within an area of proved transmission, mass treatment with amodiaquine (10 mg of base per kg of bodyweight) or chloroquine (12 mg of base per kg of bodyweight) will be instituted. If a blood smear shows *P. vivax* or *P. malariae* infections to be present, primaquine will be given daily for 14 days, starting the day after amodiaquine or chloroquine treatment. Emergency sprayings will also be carried out in houses where *A. minimus minimus* is found and in newly constructed or temporary houses. The TAMRI malariologist or entomologist will decide whether emergency spraying should be applied. In an active focus, two or more sprayings a year may be necessary.

6. *Measures to prevent importation of fresh cases of malaria.* Special teams may have to be organized to examine immigrants coming to Taiwan from other parts of the world where malaria is endemic and to find and treat carriers.

7. *Education of the public.* Now that the prevalence of malaria is waning throughout the island, people tend to think that the antimalaria campaign should be stopped. It is necessary to explain to the public the reasons why active measures must be continued and that malaria surveillance does not mean, as in often thought, simply " stand still and observe whether any new malaria cases are reported."

ACKNOWLEDGEMENTS

The staff members of TAMRI and of the WHO Malaria Team who have presented this report would like to express their appreciation of the help and advice which the organizers of the project have received from Dr C. H. Yen, Provincial Health Commissioner, Taiwan, Dr Ching Wu, Director of the National Health Administration, Republic of China, Dr T. Hsiang Wang, former Director of the National Health Administration, Dr I. C. Fang, Director of the WHO Regional Office for the Western Pacific, Dr J. Heng Liu, Chairman of the Chinese National Red Cross, Dr W. T. Yang, Surgeon General of the Chinese Army, and Mr Y. C. Chen, Secretary of the Taipeh UNICEF-WHO Liaison Office. Special recognition is due to all the hsien and township malaria workers and to the TAMRI personnel for their unabating support and enthusiasm. The assistance provided by the International Cooperation Administration (ICA), the Council for United States Aid (CUSA), and the Joint Commission on Rural Reconstruction (JCRR) is also gratefully acknowledged.

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RÉSUMÉ

Entre 1906 et 1911, le paludisme était la principale cause de mortalité à Taïwan; on lui attribuait quelque 10 000 décès annuels, dans une population de 3 millions. Les premiers essais de lutte datent de 1910. En 1942 de graves épidémies, conséquences de la guerre et du relâchement des mesures, donnèrent au paludisme un regain d'actualité. L'indice parasitaire chez les écoliers des régions septentrionales, centrales et méridionales était de l'ordre de 20-40%. Des plans de lutte, à l'échelle de l'île, furent élaborés dès 1951, et, au vu des résultats, le programme de lutte antipaludique fut transformé, en 1955, en programme d'éradication, mis en œuvre conjointement par l'Institut des recherches paludologiques, de Taïwan — successeur de l'institut créé en 1946 par la Fondation Rockefeller —, et par l'OMS, avec l'aide de l'International Co-operation Administration, du Council for United States Aid et de la Commission mixte pour la reconstruction rurale. Pour étudier l'épidémiologie du paludisme, délimiter les zones de pulvérisations, apprécier les progrès réalisés après chaque campagne annuelle de pulvérisations, et dépister les foyers de transmission subsistant dans les zones traitées, un certain nombre de techniques d'enquête parasitologiques ont été mises au point. Leur exécution a exigé une normalisation et une coordination du travail des plus poussées. La détermination de l'indice parasitaire sur les enfants d'âge préscolaire, dans quelque 150 villages des plus impaludés, celle de l'indice splénique chez les écoliers, le dépistage porte à porte pour découvrir les

cas résiduels ont constitué les principales méthodes d'enquête. L'étude des vecteurs — *A. minimus minimus* en particulier, n'a révélé aucun phénomène de résistance chez ces moustiques. On pense que d'autres espèces, *A. maculatus* notamment là où il est très dense, pourraient être responsables de la persistance de la transmission dans certains foyers.

Les auteurs décrivent l'organisation générale du programme, celle de la surveillance qui comprend le dépistage, l'étude et l'élimination des foyers résiduels de transmission, et le traitement des cas résiduels d'infection. La faible endémicité actuelle — 492 cas confirmés seulement ont été relevés en 1956 — représente cependant un potentiel épidémique et de fortes poussées pourraient se produire. Il importe donc de poursuivre les travaux épidémiologiques avec la même énergie, afin de découvrir les facteurs qui contribuent à maintenir la transmission (autres espèces vectrices, résistance des anophèles, mouvements saisonniers de la population, pulvérisations défectueuses, habitations primitives, etc.). En 1958, le programme de pulvérisations sera appliqué à diverses zones représentant environ 400 000 habitants; il sera mis en œuvre dans tous les foyers résiduels de transmission découverts ces deux dernières années, et dans toutes les régions d'hyperendémie encore peuplées d'*A. minimus minimus*, où la transmission semble persister. Après 1958, les pulvérisations systématiques cesseront, et l'on aura recours essentiellement au traitement médicamenteux des rares cas de paludisme qui subsisteront.

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