1. Introduction

A review is made of the information available up to 1971 on *Anopheles balabacensis* balabacensis. The data refer to the geographical distribution and bionomics of this malaria vector as well as to the description of the environment, and the socio-economic conditions and human ecology found in the malarious areas where *A.b. balabacensis* is the main vector of malaria. Such a review was justified in view of the fact that the antimalarial measures so far applied in these areas were only partially successful in interrupting malaria transmission. Field research on the causes of persisting transmission is systematically continued in a number of countries. This paper is thus intended to provide those investigators with the available information collected under various environmental conditions as encountered in a number of areas where this vector is present.

According to Colless (1957), Scanlon & Sanhinand (1965) and Reid (1968) the area of distribution of *A.b. balabacensis* includes Balabac and Palawan Islands in the Philippines, the northern part of the Borneo Island, the north-west corner of peninsular Malaysia, parts of Indonesia, Laos, Thailand, Kmer Republic, Viet-Nam, Burma, parts of north-east India including the Andaman Islands, Taiwan, Hainan Island and parts of Southern China. Kalra & Wattal (1962) also recorded *A.b. balabacensis* from the Island of Sumatra (Indonesia). Further details may be found in the older literature (Baisas, 1936; Baisas & Ubaldo Pagayon, 1956; Barnes, 1923; Colless, 1956, 1957; Do-Van-Quy et al, 1963; Ho Chi & Feng, 1958; Ho Chi, 1965; Kuitert & Hitchcock, 1948; Sandosham, 1962; Sandosham et al, 1963; Sheng et al., 1963; Trapido et al., 1959; Wharton, 1960). Recent findings by W. H. Cheong (personal communication) suggest that the area of distribution in West Malaysia is less restricted than was hitherto assumed.

In Thailand, *A.b. balabacensis* has been found up to 4800 feet (1460 m) altitude (Scanlon et al. 1967). The known distribution of *A.b. balabacensis* is shown in Map. 1.

2. Taxonomy

This anopheline was first described by Baisas in 1936 as *Anopheles leucosphyurus* var. *balabacensis*. TYPE LOCALITY: Balabac Island, Philippines.

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In his review of the *Anopheles leucospheirus* group, Colless (1956, 1957) raised *balabacensis* to species level and made Baisas' form into a subspecies of the same name. He showed that this *A.b. balabacensis* was widespread on mainland Asia and in Borneo though it had been recorded as *A. leucospheirus* in previous publications. *A. leucospheirus* sensu stricto was confined to a more limited territory. Some morphological differences between *A.b. balabacensis* adults from mainland Asia and the type form from Balabac Island were noted. In 1965, L. Cervone (personal communication) observed differences in pupal chetotaxy between specimens from North Malaya and from Khmer while in 1971, N. Rajapaksa (personal communication) discovered the occurrence of different wing scale patterns in adults collected from various sites in Sabah, East Malaysia.

It is possible that *A.b. balabacensis* stands for a complex of taxa in the same way that *A. gambiae* does, but in agreement with Reid (1968) the specimens from the various countries on the Asian mainland, and Borneo will be treated as belonging to the type subspecies from Balabac Island.

3. Environmental conditions in *A.b. balabacensis* areas

3.1 General

The presence of the anopheline is always associated with dense forest or forest fringes, where it finds favourable biotopes (humidity and shade). Usually it is found in high densities in hilly areas covered with thick forest, whereas its density decreases in relation to distance away from the jungle fringe.

MacArthur (1947) who discovered the role of *A.b. balabacensis* as a malaria vector was the first author to draw attention to this characteristic during his investigation in the Tambunan Valley in Sabah. Later Colless (1953a) conducted investigations in the Timbauk Valley (Sabah) and arrived at similar conclusions. During investigations carried out in 1957, Gouliouras, Pull & Keophann (unpublished WHO document) demonstrated the role of *A.b. balabacensis* as a vector of human malaria in a jungle area of Khmer. Consequently investigations of the ecology and the role of this anopheline on malaria transmission pursued or initiated in a number of countries confirmed and substantiated the initial findings.

3.2 Climate

All over its area of distribution the climate is hot all the year round but the breeding of this species is influenced by rainfall which shows considerable variation according to geographical situations. For example, in Khmer seasonal variations are evident in two annual monsoon periods, a south-west monsoon from May to October (wet season) and a north-west monsoon from November to April (relating dry season). Meteorological data referring to Snouil area are given in Annex 1.

3.3 Human habitat

The population in the forest areas lives in small villages. House built of wood, thatch and split bamboos, normally with large openings are usually raised on stilts above ground level. In jungle areas the population practises as a rule a shifting cultivation and at the time of this activity lives in rudimentary huts often made of a single roof or poles, the majority without walls. In certain circumstances (wood cutters, miners, fruit collectors) the shelters are very rudimentary, made up of any available material such as palm leaves, plastic sheets, etc.
Domestic animals are found in A.b. balabacensis areas such as cattle, pigs, dogs and poultry. As far as wild animals are concerned, deer, monkeys, squirrels, etc., could be found in varying abundance.

3.4 Human occupations favouring the transmission of malaria

Among the human occupations the following favour the contact with A.b. balabacensis of people living in villages outside its biotope: seasonal farming in the forest area; timber cutting; collection of wild fruits (which usually coincides with the transmission period); gem mining; hunting of wild animals (see Section 8.3).

3.5 Brief description of investigated areas with A.b. balabacensis

3.5.1 General

As high densities of A.b. balabacensis suitable for study are rarely encountered, the bulk of the work carried out on this vector was undertaken in only a few places such as the Pailin and Snuol areas of the Khmer Republic, Khao Mai Khao in Thailand and Tambunan Valley in Sabah, East Malaysia.

3.5.2 Khmer

The Snuol area is part of the eastern plateau covered by dense forest with tall trees and thickets of bamboo, intersected by a more or less dry scrub vegetation with fewer trees. The altitude is about 500 ft (150 m) above sea level. The climate is hot and humid, with an average daily maximum temperature of 30°C (28.6° - 34.3°C) and an average minimum of 20°C and 16.0° - 22.7°C. The highest humidity occurs in July and August (RH = 84%) and the lowest humidity in January and February (RH = 67%). The average annual rainfall amounts to about 2000 mm. Details are given in Annex 1. Seasonal variations are effected in two annual monsoon periods, a south-west monsoon from May to October, and a north-west monsoon from November to April. The population in the forest area lives in small villages with an average of 100 to 200 inhabitants. Houses are usually raised from the ground, and constructed of wood and thatch, usually with large openings. Farm huts with no walls at all make up for 20% of the total number of structures. Water buffaloes, a few pigs and some dogs are to be found in most households.

The Pailin area of the Khmer Republic is similar to Snuol, as is the Khao Mai Khao area of Thailand. The terrain is of a rolling, hilly type, and covered with dense forest.

3.5.3 Sabah

Tambunan Valley in Sabah is at an altitude of about 2000 ft (600 m). The valley is some 10 miles (10 km) long with a width varying from a quarter of a mile to two miles (0.4-3.2 km). It is well served by rivers, small mountain streams and irrigation canals. The valley floor is utilized for paddy cultivation and cattle grazing. The jungle-clad mountain sides rise abruptly from the edges of this cultivated area to summits of 5000 to 6000 feet high (1500-1800 m). The climate is equable, the temperature moderate, with a modest amount of rainfall distributed over ill-defined wet and dry seasons. Although the region is rather isolated it has a relatively dense population of around 6000 people. Population movements are very limited. Housing is of a primitive nature and the standard of living is low.

4. Bionomics

4.1 Breeding habits

A.b. balabacensis is essentially a forest mosquito, because the forest biotope ensures
optimal survival of the subspecies. The most typical breeding places are formed by pools and seepages in deep shade in the jungle, where the water is frequently freshened by rain. Larvae were found in slow running streams in Sabah, East Malaysia (Cheng), but this is not considered a typical larval habitat in other countries. Footprints made by elephants (Scanlon et al., 1967) or buffalos (Cheng), with or without dead leaves (Chow, personal communication) are common breeding sites. In south-eastern Thailand (Scanlon & Sandhinand, 1965) as well as in the Pailim area in western Khmer, sapphire mining pits filled with water from seepages or rain produce favourite breeding places for A.b. balabacensis. Larvae are often found in such pits or in pools under palm trees of the genus Salacca (Scanlon & Sandhinand, 1965) or amongst patches of carpet grass, Axanpus compressus (in Borneo, as noticed by Colless, 1956). While agreeing with the observation that typical breeding places of A.b. balabacensis are to be found in the deep shade of jungles, a number of authorities report heavy breeding in bomb craters, irrigation ditches and other water collections in partially shaded or even in sunny places (Bonne-Wepster & Swellengrebel, 1953; Keo Phann & Cervone; Cervone, personal communication; Cheng, Colless, 1956; Rajapaksa, personal communication). It seems that wherever man and his domestic animals interfere with the natural vegetation of the jungle, breeding of A.b. balabacensis will increase (Colless, 1956). According to Macan (1948) military operations in the jungle result very often in increased breeding of A.b. balabacensis.

In the laboratory, from 9% to 13% of A.b. balabacensis eggs hatched normally after having been dried slowly in a moist chamber for 15 days (Cheong & Santa Maria; Rajapaksa, 1971), while 0.6% managed to hatch after 27 days of such treatment (Rajapaksa, 1971). The last-named author was also able to breed adult A.b. balabacensis from eggs he found in dry caked mud collected from dried up breeding places. These findings suggest that A.b. balabacensis is well adapted to the temporary nature of its breeding places.

4.2 Dispersion and resting habits

There is little information about the dispersion of this species from the breeding places in the forest but it is known that A.b. balabacensis visits the villages located at short distances from the forest during the rainy period, but that during the dry period the species is restricted practically to the forest area only.

4.3 Resting behaviour

A.b. balabacensis is an exophilic mosquito. The observations on the resting habits in the forest are relatively incomplete.

4.3.1 Day-time resting

Only in Khmer, have A.b. balabacensis specimens been found and collected while resting indoors during day-time (Chow). The main day-time resting places have not yet been discovered

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5. Unpublished report on a field visit to Cambodia (Khmer), 1968.
in Khmer but it is assumed that, as in other countries, these are located in the forest. Studies in Sabah have shown that A.b. balabacensis rests among the lower parts of shrubs, under dead leaves, on well-shaded banks of streams, and other places where the light is subdued. Groups of males tend to gather near the breeding places before dusk (Rajapaksa, personal communication). In Thailand, day-time resting places are among thickets of Salacca palms or in pits dug for gem mining (Scanlon & Sandhinand, 1965). In west Malaysia specimens were found resting on deserted ant hills (Cheong, 1968).

4.3.2 Night-time resting

This has been studied in more detail. Normally, females gather around houses early in the evening (Scanlon & Sandhinand, 1965; Chow). Those that come indoors to bite often rest on the outer walls first. Once indoors, females rest before as well as after the bloodmeal. In the Khmer Republic the average resting time before feeding in unsprayed houses was 9.3 minutes and after feeding 8.1 minutes (Chow). In Sabah these times were 18.5 minutes and 53.7 minutes respectively (Chang). Indoors resting is mostly confined to the lower portions of the walls (Chang; Cheng, 1968; Cervone). The habit of gathering under the eaves before leaving at dawn was observed in Khmer (Eyles et al., 1964) and Sabah (Cheng).

The exophilic nature of A.b. balabacensis, apparent from the brief resting periods spent indoors, was further underlined by observations in unsprayed houses in Khmer where 34% of night-time resting females turned out to be blood-fed, 65% unfed and only 1% semi-gravid (Cervone).

4.4 Biting activity pattern

Day-time biting A.b. balabacensis have been recorded from Sabah, East Malaysia (Chang), Thailand (Scanlon & Sandhinand, 1965) and West Malaysia. In the last-named country two of the mosquitoes thus collected were found to harbour sporozoites (Cheong, 1968). Generally speaking, day-time biting is a rare phenomenon in this vector.

It is widely accepted that A.b. balabacensis displays its greater biting activity at night, but there is little agreement in the literature as to what is the time of peak activity.

Whole night collections of resting and biting (A.b. balabacensis at Khao Mai Khaoe in Thailand (Scanlon & Sandhinand, 1965) showed that females appeared resting soon after dusk on the vegetation which surrounds the houses. After about 20.00 hours their numbers dropped steeply while increasing numbers could be collected resting on the outer and inner surfaces of houses. Indoor biting at a low density began soon after dusk. This density increased steadily up to about 02.00 or 03.00 hours, when it started to drop again along with the density of females resting inside houses. In other areas of Thailand a similar pattern was found (Chin, personal communication) though the biting activity after midnight seemed to lessen towards the end of the breeding season (Ismail).

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1 Unpublished report on a field visit to Cambodia 1968.
2 Unpublished report on North Borneo (Sabah) 1955/58 issued in 1969.
In Sabah, the biting activity pattern was dissimilar (Chang, Cheng, 1968), and many females could be seen resting on the eaves before leaving the houses at dawn. Findings in the Khmer Republic were more or less the same (Eyles et al. 1964; Cervone, unpublished WHO report; Darwish).2

A biting activity peak after midnight was found in West Malaysia in 1965/66 (Afifi, quoted by Thevasagayam, personal communication), but catches repeated at the same spot three years later revealed peak biting taking place before 22.00 hours (Thevasagayam, personal communication). The only change in the environment had been partial deforestation and the planting of rubber trees. The findings were confirmed in West Malaysia by Cheong (1968), while also in Thailand there have been observations suggestive of a shift of peak biting activity towards the early evening (Moorhouse, unpublished document). It would be interesting to analyse in detail the various environmental factors which could influence the biting activity, so that these phenomena could be explained. Unless figures are available under comparable conditions (moonlight, wind, temperature, distance from breeding places, etc.), the possibility cannot be excluded that differences observed in the activity patterns were expressions of the variations in the environment rather than changes in the basic behaviour of the mosquitoes.

4.5 Host preferences

Man and a variety of other mammals have been used successfully to attract female A.b. balabacensis in nature. For instance, monkey-baited net traps proved very useful in field studies in the Khmer Republic (Eyles et al. 1964) and Thailand (Scanlon & Sandhinand, 1965). In the studies in the former country it was also found that cattle would attract a few A.b. balabacensis, while in the latter, the use of this type of bait was a failure. Relatively high yields of A.b. balabacensis were obtained in calf-baited traps in West Malaysia (Cheong, unpublished WHO document). In Sabah, East Malaysia, buffaloes will attract female A.b. balabacensis even in places where human bait catches may give poor results (Cheng; Chang).3 They have also been collected off orang-utans (Rajapaksa, personal communication).

Precipitin tests on stomach blood smears from fed female mosquitoes found resting in natural shelters in Sabah revealed that from 20% to 27% were of human origin (Chang).1 This suggests that in Sabah the Human Blood Index may be around 0.25. Due to a failure to detect A.b. balabacensis in its day-time resting places on mainland Asia, the data from Sabah are the only ones available.

Experiments in which unfed mosquitoes were released into a bait trap with five men and one buffalo were carried out in Sabah. They revealed that 50% of the females would feed on the men against 47% on the buffalo (Chang).1 When the experiment was repeated with only one man, in combination with a buffalo, 46% fed on the man and 54% on the buffalo (Cheng).4

Of 38 bloodfed specimens collected from a hut in the Khmer Republic which had been baited with two men, a calf and a monkey, 34% had fed on the men and 65% on the calf, the remaining specimen being reported as from an unidentified mammal (Chow).2

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1 Unpublished WHO report on North Borneo, (Sabah), 1955/58 issued in 1969.
Experiments exposing a man and a calf simultaneously, but in separate traps, were done in the Khmer Republic (Eyles et al, 1964) and in West Malaysia (Cheong). The man:calf attraction ratios thus found were 5.3:1.0 and 0.4:1.0 respectively.

It appears that A.b. balabacensis is a rather versatile feeder which will adapt itself readily to local situations when in search of blood. The high numbers of female mosquitoes attracted by buffalo baits, combined with the low percentage of human blood found in precipitin tests have led Chow (personal communication) to suggest that the Sabah populations show a higher degree of zoophily than those on the Asian mainland. However, in the absence of really comparable data from different countries more definite conclusions cannot be drawn for the time being.

4.6 Longevity, frequency of feeding and duration of the gonotrophic cycle

Observations by Cheong (personal communication) suggest that in the laboratory the average lifespan of adult A.b. balabacensis is approximately 12 days.

Observations in the field have concentrated on the study of ovarian development, but the frequency of feeding and the number of bloodmeals required for each gonotrophic cycle must also be known in order to draw definite conclusions on longevity from the proportion of females found to be parous.

In the Khmer Republic the digestion of a full bloodmeal took an average of 67 hours (range: 46-96 hours) at 27.5°C (79 females observed, Cervone, personal communication). Similar studies in West Malaysia showed that the interval between feeding and oviposition ranged from 72-83 hours (Cheong & Santa Maria, personal communication) or from 72-80 hours (Thevasagayam, personal communication). Allowing for a further time lapse between oviposition and feeding it seems that the average frequency of feeding under natural conditions may be close to once in four days. If it is assumed that one blood meal is sufficient for each gonotrophic cycle, including the first, data available from the Khmer Republic can be interpreted (with the aid of Fig. 4 in: Garrett-Jones & Grab 1964) as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Unsprayed or sprayed</th>
<th>Numbers dissected</th>
<th>Proportion parous</th>
<th>Authority</th>
<th>Our estimate of $p^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1959/62</td>
<td>U</td>
<td>4034</td>
<td>0.61</td>
<td>Cervone⁵ 1965</td>
<td>0.89</td>
</tr>
<tr>
<td>1964</td>
<td>S/3</td>
<td>150</td>
<td>0.73</td>
<td>Cervone⁵ 1965</td>
<td>0.93</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Unsprayed or sprayed</th>
<th>Number dissected</th>
<th>Proportion parous</th>
<th>Authority</th>
<th>Our estimate of ( p^* )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1963/64</td>
<td>U</td>
<td>206</td>
<td>0.84</td>
<td>Chow(^2) 1968</td>
<td>0.95</td>
</tr>
<tr>
<td>1964</td>
<td>U</td>
<td>366</td>
<td>0.86</td>
<td>Chow(^2) 1968</td>
<td>0.95</td>
</tr>
<tr>
<td>1965/66</td>
<td>S/2</td>
<td>74</td>
<td>0.63</td>
<td>Chow(^2) 1968</td>
<td>0.89</td>
</tr>
<tr>
<td>1966</td>
<td>S/2</td>
<td>87</td>
<td>0.86</td>
<td>Chow(^2) 1968</td>
<td>0.95</td>
</tr>
</tbody>
</table>

\* \( p \) = the proportion of female mosquitoes surviving through one day
\( S/2 \) = two cycles of DDT per year
\( S/3 \) = three cycles of DDT per year

Another method for estimating the longevity is to correlate the sporozoite and total infection rates in A. b. balabacensis populations. Such data could be used to estimate the daily survival rate (Macdonald, 1957). As may follow from the examples listed below, such calculations will lead to \( p \) values in the same order of magnitude as those calculated from the proportion of parous females.

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>Unsprayed or sprayed</th>
<th>Numbers dissected</th>
<th>Sporozoite rate</th>
<th>Total infection rate</th>
<th>Authority</th>
<th>Our estimates of ( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khmer</td>
<td>1957/62</td>
<td>U</td>
<td>3217</td>
<td>1.2%</td>
<td>3.7%</td>
<td>Cervone(^1) 1965</td>
<td>0.32 0.88</td>
</tr>
<tr>
<td>Khmer</td>
<td>1962</td>
<td>U</td>
<td>1218</td>
<td>1.9%</td>
<td>3.0%</td>
<td>Eyles ( et al. ) 1964</td>
<td>0.63 0.95</td>
</tr>
<tr>
<td>Khmer</td>
<td>1964</td>
<td>U</td>
<td>685</td>
<td>2.8%</td>
<td>4.8%</td>
<td>Chow(^2) 1968a</td>
<td>0.58 0.94</td>
</tr>
<tr>
<td>Sabah</td>
<td>1941</td>
<td>U</td>
<td>761</td>
<td>2.4%</td>
<td>3.3%</td>
<td>MacArthur 1947</td>
<td>0.73 0.96</td>
</tr>
</tbody>
</table>

\(^{\text{\textsuperscript{a}}}\) Various unpublished WHO documents.

These high values of \( p \), even in DDT-sprayed areas, are in agreement with the high sporozoite rates observed in this vector (see Section 6, page 11).

\(^{\text{\textsuperscript{1}}}\) Unpublished WHO document, 1965.

\(^{\text{\textsuperscript{2}}}\) Unpublished report on a field visit to Cambodia, 1968.
5. Density studies

5.1 Seasonal prevalence

In the Khmer Republic, maximum densities of *A. b. balabacensis* occur either in July and August (Keo Phann & Cervone)\(^1\) or in September and October (Chow)\(^2\) while for Thailand the same seems to be true. In West Malaysia peak densities always occur from October to December (Chow)\(^2\).

In the monsoon countries mentioned above the fluctuations in the densities observed are usually very marked. It is not uncommon that catches for adult anophelines fail to detect the presence of *A. b. balabacensis*, if carried out during the off-season, while very high densities may be recorded in the same places during the wet monsoon.

Due to a more even distribution of rainfall throughout the year, a different pattern prevails in Borneo. In Brungi a low peak may occur in March and April, and a higher peak in November and December (Chow)\(^2\). In Sabah, *A. b. balabacensis* is found the whole year round with the higher densities prevailing from July to December, but sometimes earlier as well (Colless, 1950; Chow\(^2\)). The seasonal prevalence of vector densities has an important bearing on the dynamics of transmission.

5.2 Man-biting rate

It will be clear from the foregoing that it is impossible to give one figure which expresses the man-biting rate of *A. b. balabacensis*. However, this vector is characterized by low biting densities during periods of active malaria transmission. For instance, in the Khmer Republic (Eyles et al., 1964) it was observed that the man-biting density indoors was equal to 2.0 per man per night, and outdoors 3.6. It was noted that "all the people seemed to remain indoors after dark". That active transmission was going on at the time (October) was proved by the fact that three of the seven members of Eyles' team contracted falciparum malaria in the course of the studies. It seems therefore that it is reasonable to assume that *A. b. balabacensis* is capable of transmitting malaria at a man-biting rate of 2.0, at least in this part of the Khmer Republic (Pailin).

6. Vectorial status

In older publications under the name of *A. leucosphyrus*, *A. b. balabacensis* has been incriminated as a vector of malaria in India (Clark & Choudhury, 1941), Burma (Kuitert & Hitchcock 1948; Macan, 1948), Borneo (McArthur, 1947), Thailand (Ayurskitkosol & Griffith, 1963; Scanlon & Sandhinand, 1965), the Khmer Republic (Gouliouras et al.)\(^3\) and the north of West Malaysia (Sandosham et al., 1963).

Sporozoite rates are often rather high, as may follow from the following examples:

<table>
<thead>
<tr>
<th>Country</th>
<th>Number dissected</th>
<th>Sporozoite rate</th>
<th>Authority</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sabah</td>
<td>761</td>
<td>2.4%</td>
<td>McArthur, 1947</td>
<td></td>
</tr>
<tr>
<td>Sabah</td>
<td>876</td>
<td>2.9%</td>
<td>Colless, 1952</td>
<td></td>
</tr>
<tr>
<td>Sabah</td>
<td>3271</td>
<td>1.74%</td>
<td>Change, 1969(^2)</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Unpublished WHO document, 1963
\(^2\) Unpublished WHO document, 1968
\(^3\) Unpublished WHO document, 1957
<table>
<thead>
<tr>
<th>Country</th>
<th>Number dissected</th>
<th>Sporozoite rate</th>
<th>Authority</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khmer Republic</td>
<td>233</td>
<td>0.9%</td>
<td>Gouliouras, Pull &amp; Keo Phann, 1957&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Khmer Republic</td>
<td>3217</td>
<td>1.21%</td>
<td>Keo Phann &amp; Cervone, 1963&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Khmer Republic</td>
<td>2431</td>
<td>1.85%</td>
<td>Lachance, 1963&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Forest area</td>
</tr>
<tr>
<td>Khmer Republic</td>
<td>880</td>
<td>0.6 - 1.0%</td>
<td>Eyles et al. 1964</td>
<td>Unsprayed village area in medicated salt project</td>
</tr>
<tr>
<td>Khmer Republic</td>
<td>338</td>
<td>2.4 - 7.6%</td>
<td>Eyles et al. 1964</td>
<td></td>
</tr>
<tr>
<td>Khmer Republic</td>
<td>685</td>
<td>2.8%</td>
<td>Chow, 1968&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Unsprayed area</td>
</tr>
<tr>
<td>Khmer Republic</td>
<td>364</td>
<td>0.0%</td>
<td>Chow, 1968&lt;sup&gt;a&lt;/sup&gt;</td>
<td>DDT-sprayed area</td>
</tr>
<tr>
<td>Khmer Republic</td>
<td>237</td>
<td>2.1%</td>
<td>Darwish, 1968&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Unsprayed area</td>
</tr>
<tr>
<td>Khmer Republic</td>
<td>373</td>
<td>1.3%</td>
<td>Darwish, 1968&lt;sup&gt;a&lt;/sup&gt;</td>
<td>DDT-sprayed area</td>
</tr>
<tr>
<td>Viet-Nam</td>
<td>176</td>
<td>2.3%</td>
<td>Nguyen Thuong Hien, 1968</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>859</td>
<td>3.4%</td>
<td>Clark &amp; Choudhury, 1941</td>
<td></td>
</tr>
<tr>
<td>Thailand</td>
<td>335</td>
<td>8.7%</td>
<td>Scanlon &amp; Sandhinand, 1965</td>
<td></td>
</tr>
<tr>
<td>Thailand</td>
<td>not given</td>
<td>6.7%</td>
<td>Scanlon &amp; Sandhinand, 1965</td>
<td></td>
</tr>
<tr>
<td>Thailand</td>
<td>not given</td>
<td>6.0%</td>
<td>SEATO, quoted by Scanlon et al. 1967</td>
<td>Cheong, 1968&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>West Malaysia</td>
<td>3349</td>
<td>3.0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Various unpublished WHO documents

The finding of high sporozoite rates, even in DDT-sprayed areas (Darwish, 1968) is significant. On Labuan Island, Sabah, Colless (1952) found a positive correlation between the biting density and the sporozoite rate. This suggested that factors favouring population density and those favouring the survival rate may have been operative simultaneously.

Some of the records on sporozoites found in *A. a. balabacensis* may relate to simian plasmodis rather than human forms. Many authors (e.g., Cheong et al., 1965; Collins et al., 1967) have demonstrated that this mosquito acts as a very efficient vector of several species of simian...
malaria. It has also been shown in the laboratory that A.b. balabacensis is capable of transmitting Plasmodium knowlesi (H strain) from monkey to man (Chin et al., 1968). However, several of the figures given in the above list were from areas where monkeys were not found, or from areas where A.b. balabacensis was distinctly anthropophilic.

In the case of sporozoites found in DDT-sprayed areas, the question whether these could be of simian origin is irrelevant as the longevity of the local mosquitoes appears to be insufficiently affected by the insecticide and successful incubation of plasmodia is still possible.

6.1 Inoculation rate

In few other malaria vectors is the combination found of high daily survival rate, low frequency of feeding and high human blood index which is assumed for A.b. balabacensis. This combination of characteristics renders this mosquito extremely efficient as a vector of malaria. It also explains the high degree of endemicity that can be found in areas where the biting density of A.b. balabacensis may be less than one bite per man per night.

The experiences of Eyles' team in the Khmer Republic in October 1962 led to an estimate of the annual attack rate of 16 000 per 1000 population, which was based on an inoculation rate of three per 68 man-days, or 0.044. The entomological data collected by the team (Eyles et al. 1963) showed that each member would have been exposed to about 3.6 bites per night. Since the sporozoite rate, s, was found to be 4.4%, the expected inoculation rate would be 3.6 x 0.044 = 0.1584. The discrepancy between the inoculation rate calculated from the entomological approach, and the inoculation rate actually experienced, expressed as a fraction 0.044/0.1584 or 0.27, shows the proportion of infective bites actually resulting in infection. While this may seem rather low, it should be borne in mind that although the team was composed of non-immunes, they were all under chloroquine chemoprophylaxis.

6.2 Reproduction rate

The information collected in Pangrolin, a village in the Pailin area of Khmer (Eyles et al. 1964) provided the following data:

(a) man-biting rate = 2
(b) p = 0.95 (based on 1218 dissections)
(c) HBI estimate = 0.75 (assumption based on the man : calf attraction ratio of 5:3)

From this information an idea of the basic reproduction rate in this area and at that time can be worked out as follows:

A patient suffering from falciparum malaria is assumed to be infective to all the vectors which feed on him during 60 days. Being bitten by two A.b. balabacensis each night he originally infects 160 vectors. The probability of survival through one day being 0.95 and the temperature being favourable for the completion of the extrinsic cycle in 12 days, 54% of them will survive until the development of sporozoites and these will have a subsequent expectation of (infective) life of 20 days. The vector feeding once every three days and being largely anthropophilic (HBI of the order of 0.75), each survivor will convey the infection to five people (20 x 1/3 x 75/100). Through this mechanism and despite the very low vector density 432 new infection will be distributed in the population from the primary case.
As would be expected with a vector with a frequent man-biting habit and an extended longevity at temperatures favourable for the rapid completion of the extrinsic cycle, the type of malaria encountered is stable with high endemities and stable immunity.

Under such conditions it is admitted that the vector density needed to maintain transmission is very low, of the order of one bite every 40 nights per person or even less (Macdonald, 1957).

7. Malaria in A. b. balabacensis areas

7.1 Endemicity

The high endemicities prevailing in the dense jungle areas are an expression of the intensity of malaria transmission maintained by A. b. balabacensis.

In Sabah, McArthur (1947) reported spleen rates of nearly 100% in children in the forested hills and valleys of the Tambunan area.

In the Khmer Republic, Huehne gave spleen rates of about 75% in the forested district of Pailin, one month after the third cyclical DDT spraying. From the same country, Farid recorded spleen rates of 65% in schoolchildren (7-12 years) examined in the Snoul pilot project after the fourth six-monthly spraying cycle. Scanlon & Sandhinand (1965) noted spleen rates of 75% in village children at the foot of Khao Yai mountain and 66% among infants in the forested area around Khao Mai Khaoe in Thailand.

In Snoul, Khmer Republic, the infant parasite rate in June 1965 was 20.5% (522 examined) while the parasite rate in children from two to nine years was 34.8% (1162 examined) with a species distribution of 65% P. falciparum, 30% P. vivax and 5% P. malariae. In the two villages in the Pailin area of the same country, where Eyles et al. (1964) carried out their mosquito dissections, the overall parasite rate was 50.5% (99 examined) with a predominance of P. falciparum.

The above figures serve to illustrate that the high endemicity rates, typical for malaria transmitted by A. b. balabacensis, prevail in areas covered by dense jungle which forms the habitat required by this vector.

7.2 Distribution of malaria in relation to the forest

The correlation between presence or nearness of dense forest on one side and the degree of endemicity on the other side appears to be the common denominator of most publications on A. b. balabacensis.

McArthur (1947) was the first author to draw attention to this characteristic. He carried out a survey of 25 villages starting in the centre of Tambunan Valley and working outwards to the jungle fringe and further up into the inhabited ravines. It was found that villages located amongst the rice fields in the centre of the valley were less malarious, with spleen rates in children of about 20%, but that malaria increased steadily on approaching the surrounding hills until in the forested ravines the spleen rate of children was 100%.

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2 Unpublished WHO report on a field visit to Cambodia, issued 1967.
The least malarious villages were those farthest from the hills, and the most malarious were those in the hills. To this rule McArthur found one peculiar exception, for which no explanation could be found for some time. In the north-west of Tambunan Valley there was a ravine, typical except for the fact that it was more open than the others in the area. Two villages, Sunsurun and Tantalob (see map, Annex II) were located in this ravine and in accordance with the rule it was expected that both would be highly malarious, probably with spleen rates near 100%. On examination it was found that Tantalob had, in fact, a spleen rate of 100% but Sunsurun, less than half a mile away and within sight of it, yielded, surprisingly, a spleen rate of only 24%. Later on, the discovery of *A.b. balabacensis* as the vector explained this peculiar distribution of malaria endemicity. It turned out that the hilly areas were malarious, not because they were hilly, but because they were covered with dense jungle. Only in Sunsurun had this jungle been cleared, rendering this locality much less malarious in comparison with the others.

In the Timbau Valley, also in Sabah, Colless (1953<sup>a</sup>) found that no enlarged spleens could be detected at a distance of 790 yards (710 metres) or over from the forest when breeding places were very abundant. In areas where *A.b. balabacensis* breeding was less intense, enlarged spleens could be found only in places much closer to the forest.

In the Khmer Republic, spleen rates were about 65% in the forested parts of the Snuol pilot project after four spraying cycles, while no spleen enlargements at all were detected in a neighbouring village in a rubber estate. Even in the absence of spraying, blood parasite surveys carried out in the centre of this estate showed negative results. In June 1969, in the unsprayed rubber estate villages of Chivat and Kamlek (located respectively at 1500 metres and less than 500 metres from the jungle) the parasite rates in children of five to 14 years were 3.2% (122 examined) and 12.1% (115 examined) respectively, while in the nearby sprayed jungle villages of Mak Kandal and Kbal Lumpou these rates were 46.4% (28 examined) and 70.8% (24 examined) respectively, according to Colombo (personal communication, 1969).

From the Fang district of Thailand, Avery Jones<sup>1</sup> also reported that in the forested hilly part of a village perched on the fringe of the jungle, the spleen rate was 36% with a parasite rate of 42% (in 28 children) while in the other part of the same village, which was surrounded by open terrain, the spleen rate was 5% and the parasite rate was also 5% (in 20 children). This author concluded: "It seems that only villages actually in contact with hills and forests need to be sprayed. No evidence was found of transmission in villages as close as half a kilometre to the hills".

Similar observations were made elsewhere in Thailand by Avery Jones. According to this source, three types of arboreal vegetation could be recognized in the Korat district, as follows:

**Type A:** was dense jungle on or near hills. Here the children's parasite rates varied from 30% to 80% with an average of 64%. In a group of villages which had been sprayed with DDT and dieldrin for three years the parasite rate in children who had never left the area was still 59% (89 examined).

**Type B:** originally had the same vegetation as Type A, but was partially cleared by the cutting of trees. In unsprayed villages the parasite rates varied from 5% to 30% depending upon the degree of deforestation and the distance from vegetation Type A.

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<sup>a</sup> Various unpublished WHO documents.
Type C: was flat land with dry sandy soil and scattered shrubs, short trees and small thickets of bamboo. Humid, shaded undergrowth does not occur. Unsprayed villages in such areas showed a parasite rate of only 0.6%.

As pointed out already, the highest endemicities are encountered only in the forest because A.b. balabacensis is a jungle breeder, and even the adults require the jungle biotope for optimal survival. Its vectorial importance decreases as the distance from the jungle fringe increases within a range of about one mile (1600 metres), while no adults are to be found beyond that range. The endemicity pattern resulting from this could serve as a typical example of "landscape epidemiology" described by Pavlowsky (1966).

8. Response to control measures

8.1 DDT spraying

In the Snuol pilot projects of 1955-1959 and 1965-1967, where parasitological and entomological studies were integrated, it was shown that DDT spraying would not interrupt transmission, even when supplemented by mass drug administration. In this area the infant parasite rate in May 1954, i.e., before spraying, was 16% (127 examined). After two six-monthly cycles of 2 gm DDT wdp/m² A. minimus had practically disappeared, but in May 1957 the infant parasite rate was still 5% (322 examined). Systematic dissection of A.b. balabacensis revealed that this mosquito was maintaining transmission.

In 1958 a combination of DDT spraying and weekly mass drug administration (four distributions of chloroquine, 12 of pyrimethane and 33 of chloroquine) failed to interrupt transmission. When the mass drug administration was discontinued in December 1958, the infant parasite rate in the following month was still 2% (289 examined). In 1959 only spraying with DDT took place. Two months after the second cycle was carried out that year, 17 new infections were found among 279 infants examined. Nine of these cases probably had been infected in unsprayed farm huts, but eight of the infants had never left the sprayed villages (Antimalaria Co-ordination Board, 1961).

In 1965, another pilot project covering a population of 114,000 people was carried out in the Snuol area. The basic method of DDT wdp. spraying at the rate of 2 gm/m², was carried out twice a year, in May and October. Every attempt was made to obtain the most perfect coverage possible under the circumstances. As a result, about 98% of ordinary houses and 98% of all temporary huts could be assumed to have been sprayed. Analysis of the results showed:

(a) a considerable reduction in A.b. balabacensis density;

(b) a decrease in the infant parasite rate from 4.4% in June 1965 to 0.8% in June 1966, and 1.1% in June 1967.

(c) a decrease in the immunity, as the percentage of P. falciparum infections accompanied by gametocytes in the age-groups of five to 14 years increased from 21% in 1965 to 36% in 1967, and also the specific P. falciparum gametocyte index increased from 5.2% in 1965 to 8.4% in 1967;

(d) a decrease in the parasite rate in the age-group of five to 14 years in the first year, followed by an equal increase in the second year (33.5% in 1965, 21.0% in 1966, 32.6% in 1967).

For details see Annexes II and III.
In other words, although there was a decrease in the amount of transmission, a concurrent decrease in the immunity had the effect of neutralizing the benefits of this. As pointed out by Macdonald (1957): "Any decrease in transmission in a place where immunity is playing an important role inevitably results in a decrease in the immunity and a relative increase in the gametocyte reservoir restoring the net reproduction rate to very much the same level as prevailed beforehand - the results may be most disappointing, marked by considerable decrease in anopheline prevalence and in the inoculation rate as recorded by entomological means, but by only small changes in the human picture."

The best results were obtained in three estate villages of Snuol, where the parasite rate dropped from 20% (171 examined) in 1965 to 3.8% (285 examined) in 1967. These places, however, had been deforested during the same period. In the centre of the Snuol rubber estates, the parasite rate was zero even before the resumption of the pilot project (178 examined).

Analysis of the entomological data from the Snuol project shows

(a) inside DDT-sprayed huts the numbers of A.b. balabacensis biting one man in one day was 0.04 as against 1.18 before spraying, the outdoor biting density dropped from 0.95 before spraying to 0.60 after spraying,

(b) similarly, the indoor resting density decreased dramatically from 1,740 collected per man per night to 0.005 per man per night,

(c) three out of four A.b. balabacensis collected in a window trap attached to a sprayed house 50 days after the fifth spraying cycle survived for 24 hours, while the fourth specimen even lived for 52 days afterwards (Soong, 1966).

(d) while before the resumption of spraying the sporozoite rates in three capture stations had been 1.37%, 2.96% and 8.16%, only one oocyst was found after spraying (364 examined) (Ruff & Pull)\(^1\) and in June 1968 one mosquito was found with sporozoites (two examined) (Darwish).\(^2\)

Behaviour of individual A.b. balabacensis in a DDT-sprayed wooden house in Sabah was studied by Colless (1953b). When DDT wdp. was used as a 2% suspension this author found that 20% of A.b. balabacensis which entered left again without feeding on the human bait while only half of those which did feed rested subsequently. The average period of rest, before and after feeding, was observed to be only two minutes.

Later on, Cheng (1968), working with four experimental huts situated in a jungle area in Sabah, showed that even in completely and recently sprayed four-walled huts A.b. balabacensis was still able to enter, bite and to a relatively great extent survive.

The same picture was found in the Khmer Republic where in 1959 in an isolated village (8 km from the nearest village) experimental huts were sprayed with DDT under strict supervision, along with the 20 or so local houses of the villagers, at a rate of 2 gm/m\(^2\).

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After spraying, the density of *A.b. balabacensis* was reduced, both in unsprayed and sprayed huts. In DDT-sprayed experimental huts, the mortality ranged from 83% to 93% within the first month after spraying, but the control mortality observed in an unsprayed hut jumped from 5% to 35-41% during the same period. This phenomenon was attributed to mosquitos having picked up lethal dosages of the insecticide in surrounding houses (Chow). On the other hand, a number of mosquitos from the window trap of a sprayed house lived for four to five days, and one of these was found positive for oocysts (12 days after the spraying) and another one had sporozoites in its salivary glands (24 days after the last spraying) (Chow, personal communication).

As in Sabah, the well-sprayed experimental huts or even the better quality local houses in the capture stations in the Snouol area of the Khmer Republic allowed *A.b. balabacensis* to enter, bite and escape lethal contact with the insecticide.

It cannot be expected that the situation will be better in the poorly built structures with incomplete walls or even without walls altogether. Moreover, it is evident that not all the people will stay in these structures the whole night. Therefore, transmission could be expected to take place out of doors even in well sprayed villages, or in temporary farm huts without walls, even if these are sprayed (roof and poles only). In the Khmer Republic where the women attended evening classes in reading and writing, investigations of positive infants showed that transmission could have taken place when their mothers carried them to the local school which consisted of a shelter without walls.

An epidemiological assessment of the efficacy of six-monthly DDT spraying in combination with good surveillance was carried out in a village near Tenom, Sabah (Ch'en). Spraying was done in July and August, 1967, covering 146 of the existing 150 houses and all the four temporary huts. The operations were repeated in February and March, 1968, covering 150 of the then 154 houses and all of the 14 temporary huts. The four village houses left unsprayed at each round were not inhabited.

In the months preceding the spraying in 1967, 23 cases of malaria (19 *P. falciparum* and four *P. vivax*) were found in 476 slides taken. After spraying, one indigenous case of *P. vivax* was found in November 1967 and another three in January 1968. After the second cycle one indigenous *P. vivax* case was found in May, followed by four more, and four indigenous cases of *P. falciparum* in June and July, 1968. Three months after each cycle *A.b. balabacensis* had resumed biting indoors. It would appear that transmission was not interrupted despite the 97.5% spraying coverage and adequate case detection with radical treatment given to all confirmed cases.

Up to the present there has been no indication of insecticide-resistance in *A.b. balabacensis*.

### 6.2 Dieldrin spraying

According to Chang studies in two experimental areas in Sabah revealed that dieldrin applied once or twice a year at a rate of 0.6 gm/m² did not produce any better results than DDT at a rate of 2 gm/m². In the two areas, the epidemiological situation was affected, but in neither of them was transmission interrupted. While dieldrin induced a higher mortality in entering *A.b. balabacensis*, DDT resulted in a greater reduction of the indoor biting density. The net effect on transmission was the same.

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1 Unpublished WHO report on a visit to Cambodia, 1960.
3 Unpublished WHO assessment report on North Borneo (Sabah) 1955/58, issued in 1969.
8.3 Effects of housing standards and human ecology

The majority of the native houses in the jungles of South-East Asia are raised on wooden poles, three to six feet (one to two metres) off the ground, with bamboo ladders or notched tree trunks used to enter. Floors are often made of plaited bamboo, and roofs of woven palm thatch. The walls are either of plaited bamboo or of palm thatch, seldom of wood. The size of jungle villages is usually limited to between 25 and 50 houses of a temporary nature. The average life of a local hut is approximately two years, which means that between the intervals of spraying cycles, if spaced six months apart, 25% of the huts will be rebuilt or at least repaired. Pioneer huts of new settlers may consist of only a thatch roof supported by poles, without walls.

The farm huts which make up between 20 and 25% of the total number of structures in the Khmer Republic are also usually without walls. They are built adjacent to the cultivated lands, normally paddy fields, before the actual planting season starts. Whole families may sleep in such huts if crops are grown at sites far from the village. Thus, many structures in the typical A.b. balabacensis biotope provide for numerous openings through which the vector can enter and leave freely.

Farming in these jungle areas results in people moving between villages and semi-permanent farm huts. While these huts may pose serious operational obstacles, in theory they can all be found and subsequently sprayed.

In addition to farming there are a number of related activities which bring people into the forest without constructing shelters at all. Hunting is one example, and certain game animals are hunted during the night because of their nocturnal habits. In Thailand and the Khmer Republic mining (for precious stones) is carried out in forested areas and often at night, for reasons of secrecy. Certain types of palm fruits are collected from the forests of Thailand during a specific season (Ismail)¹ and so are cardamom seeds in Khmer, or durians and cinnamon bark in Sabah. Logging activities will also expose people to forest conditions for long periods without the benefit of good shelter. Workers on such ventures may sleep in tents, or under a sheet of plastic, or simply in the open. There are no surfaces where DDT could be applied to protect these people from the intense contact with A.b. balabacensis populations which must undoubtedly exist in many of these areas.

8.4 Response to antimalarial drugs

Because of the failure of DDT in the A.b. balabacensis area, and in view of the operational problems of mass drug administration, a medicated salt project was launched in the Pailin area of the Khmer Republic in 1960. The population covered was approximately 20,000. Sea salt was mixed locally with pyrimethamine at a concentration of 0.05% w/w and between January 1960 and June 1961, 77 tons of this salt were distributed in the area. When it was noticed that some cases of P. falciparum did not respond to pyrimethamine this drug was replaced by chloroquine at a concentration of 0.6% w/w in sea salt, and 75 tons of this new mixture were distributed between June 1961 and November 1962. In two indicator districts the parasite rates decreased respectively from 40% to 17% and from 27% to 14%. However, in October 1962 a parasite survey carried out in the two project villages of Sur Sdei and Pangrolin revealed a parasite rate of 50.5% (Eyles et al. 1963).

The failure of the chloroquinized salt was attributed by Huehne, Cervone & Keo Phann (quoted by Ruff & Pull)² to an irregular distribution of the salt. It is not unlikely

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that drug resistance is also partly responsible for the failure. The fate of three of the seven members of Eyles' team has already been mentioned. One of these suffered from falciparum malaria which was reported to be resistant to chloroquine. This strain was subsequently named the Cambodia II strain (Eyles et al. 1963). Four years later, Pallin infections of P. falciparum were still reported to show some RII resistance levels (WHO, 1967). Further studies on possible alternative treatments indicated that P. falciparum resistant to chloroquine may become resistant very quickly to the association of DDS and pyrimethamine, with cross resistance to the association of sulfadoxine and pyrimethamine (Verdrager et al. 1969). This phenomenon has recently been confirmed in the USA using volunteers infected with the Malayan III and Thai II strains (Chin et al. 1970).

The exact geographical extent of chloroquine resistance in P. falciparum in South-East Asia is uncertain but seems to coincide with the presence of A.b. balabacensis. The early observation of Eyles et al. (1963) that A.b. balabacensis appears to be a vector in all the areas where the phenomenon of chloroquine resistance has been detected still hold true. The distribution of known or suspected strain of chloroquine resistant P. falciparum associated with A.b. balabacensis is summarized in map No. 2 (adapted from Peters, 1969).

8.5 Evidence of success of control measures

There is evidence of interruption of transmission by A.b. balabacensis in Brunei and in limited areas of Sabah.

Brunei. The annual parasite incidence in 1965, the last year of the Brunei pre-eradication programme, was considered as the baseline of pre-operational endemcity in the state (Miyairi).1 It amounted to 3.21 cases per thousand, (Annual Blood Examination Rate: 4.5%). The actual number of cases was 104, of which 102 were considered indigenous (18 P. falciparum, 10 P. vivax, 73 P. malariae and one mixed infection) and two were imported. Following spraying in 34 villages in 1965 and another 264 villages in 1966 (DDT emulsion 25%, twice a year) the number of cases dropped to 24 in 1966 and 18 in 1967. Spraying coverage was about 88%. Temporary huts are relatively rare (7%) and 84% of all structures were made either of wood or concrete or both. The sole vector of malaria in Brunei is A.b. balabacensis. Its indoor densities dropped to almost zero after the first round of spraying.

It appears that in Brunei, which is at the fringe of the area of distribution of A.b. balabacensis, this mosquito may be a relatively poor vector. The good average standard of housing and the predominance of P. malariae may have played their roles in achieving such a degree of success.

Sabah. Only in Keningau district and on Labuan island, interruption of transmission was presumed in 1960 after three years of spraying with dieldrin and the application of mass drug administration (Gramiccia & Miranda-Franco).2

In Keningau south, two cycles a year of spraying of dieldrin were carried out from 1957 up to and including 1961, associated with chloroquine-pyrimethamine distributions except in 1960. In Labuan island there is a second vector, A. sundaiacus. The island was sprayed with one cycle of dieldrin a year at a rate of 0.5 gm/m² from 1955 until 1957, and subsequently with the same insecticide but two cycles a year, and at a dosage of 0.6 gm/m², from 1958 until 1960. Combined chloroquine-pyrimethamine tablets were distributed at each cycle.

These relatively good results obtained in Brunei and parts of Sabah seem to contrast sharply with the picture in most of the other A.b. balabacensis areas. It must be assumed that local conditions are likely to be mainly responsible for the difference. As we have already suggested, Brunei is on the outskirts of the A.b. balabacensis area, and it could be that the subspecies is badly adapted to the local environment resulting in a low reproduction rate. Here, a relatively slight reduction in the mosquito’s longevity, or its biting rate could be sufficient to interrupt transmission. Considering the good quality of the houses DDT spraying alone could well be sufficient. On the other hand, the same quality of spraying operations applied in the Khmer Republic might result in failure (in fact it did) because the basic reproduction rate is so much higher and a poorer type of housing prevails providing the vector ample openings for entry and escape.

In Sabah, as a whole, it can be said that the best results with insecticides were obtained in the areas with the lowest endemicity, the best quality of housing and the most intense animal husbandry, such as one finds along the coastal plains or in partly deforested areas with stable populations (Chang).\(^1\) Where transmission continues, the original endemicity was high, houses are of a poor quality, and domestic animals are less abundant.

9. The need for further investigations

In order to acquire a better understanding of the epidemiology of malaria transmitted by A.b. balabacensis, and in order to find more efficient means of dealing with it, a number of subjects need further study. The following are listed as being the most important:

(a) the possible existence of an A.b. balabacensis species complex;

(b) the possible differences in the man-biting habit of A.b. balabacensis on mainland Asia and in Sabah, East Malaysia;

(c) the behaviour of A.b. balabacensis in various types of structures, but especially the more "open" ones, in the absence and presence of different insecticides;

(d) the effect of the distance between houses and the forest, and the effects of housing conditions and human ecology on transmission and the prospects of its interruption. More information on the dispersion of this subspecies from its breeding places might be obtained using ultra-violet light traps with dry ice;

(e) the effect of drugs, or combinations of drugs, in combination with insecticides. This should include a drug with an effect on the gametocyte reservoir.

10. Conclusions

As pointed out by Macdonald (1957) A.b. balabacensis appears to possess the characteristics of longevity and anthropophily necessary to maintain the transmission of stable malaria. The effect of this type of malaria resembles the African picture. Due to the limitation of A.b. balabacensis to the forest biotope, the most severe conditions prevail only in areas actually covered by jungles.

\(^1\) Unpublished WHO assignment report in North Borneo (Sabah) 1955/58, issued in 1969.
It is in this typical biotope that DDT spraying fails to bring the reproduction rate down sufficiently, because of the high vectorial capacity of A.b. balabacensis, its exophilic character, the poor standards of housing, and the primitive nature of the human ecology. Here the net effective reproduction rate might be brought below the critical level by introducing additional measures, acting on the gametocyte reservoir, and by replacing DDT with an insecticide which inflicts higher mortalities but which has no repellent effect.

It would be unrealistic to ignore the fact that wherever A.b. balabacensis transmits malaria in areas not representing its typical jungle biotope, and where the houses may be of a better quality, DDT may well achieve interruption of transmission. To delimit such areas for subsequent implementation of classical malaria eradication measures would reflect the wisest policy applicable at present.

RESUME


Cet anophèle se rencontre toujours dans les zones de forêt dense ou en bordure de celles-ci, car il trouve dans ces biotopes des conditions d'humidité et d'ombre qui lui sont particulièrement favorables. Sa densité atteint généralement son maximum dans les zones accidentées très boisées et diminue en fonction de l'éloignement de la lisière de la jungle.

Il semble que A. b. balabacensis possède les caractéristiques de longévité et d'anthropophilie indispensables pour le maintien d'une transmission durable du paludisme. Etant donné que la forêt est le biotope exclusif d'A. b. balabacensis, les conditions les plus dangereuses se trouvent réunies uniquement dans les régions effectivement recouvertes par la jungle.

Dans ce biotope caractéristique, les pulvérisations de DDT ne réussissent pas à abaisser suffisamment l'indice de propagation de la maladie, vu la très haute capacité vectorielle d'A. b. balabacensis, ses habitudes exophiles, les conditions de logement précaires et la nature primitive de l'écologie humaine. Dans ce cas particulier, il faudrait, pour pouvoir abaisser l'indice réel de propagation au-dessous du seuil critique, appliquer des mesures additionnelles, agissant sur le réservoir de gamétocytes, et remplacer le DDT par un insecticide sans effet répulsif qui entraîne une mortalité plus élevée.

Dans les régions où A. b. balabacensis transmet le paludisme sans y trouver son biotope typique - la jungle - et où les habitations sont de meilleure qualité, il est fort probable que l'on peut interrompre la transmission à l'aide du DDT. Délimiter ces régions afin d'y appliquer les mesures classiques d'éradication constituerait, dans les circonstances présentes, la politique la plus avisée.

On ignore quelle est exactement la distribution géographique de la résistance à la chloroquine chez P. falciparum en Asie du Sud-Est, mais il semble qu'elle coïncide avec celle d'A. b. balabacensis.
Pour mieux connaître l'épidémiologie du paludisme transmis par A. b. balabacensis et découvrir des moyens de lutte plus efficaces, il convient d'approfondir l'étude de certains problèmes, dont voici les plus importants :

a) Existence possible d'un complexe d'espèces A. b. balabacensis.

b) Différences éventuelles dans les habitudes anthropophiles de A. b. balabacensis en Asie continentale et à Sabah (Malaisie orientale).

c) Comportement d'A. b. balabacensis dans divers types de constructions, notamment dans celles du type le plus "ouvert", en l'absence et en présence de différents insecticides.

d) Effets de l'éloignement des habitations par rapport à la forêt et effets des conditions de logement et de l'écologie humaine sur la transmission et les possibilités de l'interrompre. On pourrait obtenir davantage de renseignements sur l'aire de dispersion de cette sous-espèce autour de ses gîtes larvaires d'élection en utilisant des pièges à lumière ultraviolette contenant de la glace sèche.

e) Effet de l'administration de médicaments, ou associations de médicaments, parallèlement aux pulvérisations d'insecticides. Les essais de chimiothérapie devraient comporter l'emploi d'un produit agissant sur le réservoir de gamétocytes.
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Map 1. DISTRIBUTION OF A. B. BALABACENSIS IN SOUTHERN ASIA
Map 2. APPROXIMATE AREAS IN WHICH CHLOROQUINE RESISTANT STRAINS OF P. FALCIPARUM ARE IN SOUTH-EAST ASIA IN ASSOCIATION WITH A. B. BALABACENSIS (BARRED AREAS)

Adapted from Peters, 1969
METEOROLOGICAL DATA, SNUOL (KHMER REPUBLIC)
(average over the period 1958-1968)

<table>
<thead>
<tr>
<th>Month</th>
<th>Temperatures °C</th>
<th>Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum (1200 hours)</td>
<td>Minimum (0700 hours)</td>
</tr>
<tr>
<td>January</td>
<td>28.7</td>
<td>16.0</td>
</tr>
<tr>
<td>February</td>
<td>32.3</td>
<td>19.2</td>
</tr>
<tr>
<td>March</td>
<td>33.5</td>
<td>19.4</td>
</tr>
<tr>
<td>April</td>
<td>34.3</td>
<td>21.9</td>
</tr>
<tr>
<td>May</td>
<td>32.7</td>
<td>21.9</td>
</tr>
<tr>
<td>June</td>
<td>31.0</td>
<td>21.6</td>
</tr>
<tr>
<td>July</td>
<td>30.1</td>
<td>21.6</td>
</tr>
<tr>
<td>August</td>
<td>29.8</td>
<td>21.7</td>
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<tr>
<td>September</td>
<td>28.6</td>
<td>21.6</td>
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<tr>
<td>October</td>
<td>30.5</td>
<td>22.3</td>
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<tr>
<td>November</td>
<td>31.7</td>
<td>22.7</td>
</tr>
<tr>
<td>December</td>
<td>30.9</td>
<td>20.6</td>
</tr>
</tbody>
</table>
CHANGES IN PARASITE RATES,
SNUOL PILOT PROJECT (KHMER REPUBLIC)

Total population of pilot project area on 31 December 1965 ... 114 000
Total population of pilot project area on 31 December 1966 ... 119 720
Number of villages in pilot project area ... 356

First spraying: May 1965
Two cycles a year, in May and October

Number of villages examined in June 1965, June 1966, June 1967: ... 36
Population in these 36 villages, on 31 December 1965, 31 December 1966

<table>
<thead>
<tr>
<th></th>
<th>5-9 years</th>
<th>10-14 years</th>
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<tbody>
<tr>
<td>June 1965</td>
<td>1213</td>
<td>1262</td>
</tr>
<tr>
<td>June 1966</td>
<td>1038</td>
<td>1092</td>
</tr>
<tr>
<td>June 1967</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Age (yrs)</th>
<th>No. of slides</th>
<th>% pos.</th>
<th>Parasite spec.</th>
<th>Gametocytes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>exam.</td>
<td>pos.</td>
<td></td>
<td>f</td>
</tr>
<tr>
<td>June 1965</td>
<td>5-9</td>
<td>752</td>
<td>262</td>
<td>34.8</td>
<td>182</td>
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<tr>
<td></td>
<td>10-14</td>
<td>489</td>
<td>154</td>
<td>31.5</td>
<td>98</td>
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<tr>
<td></td>
<td>5-14</td>
<td>1241</td>
<td>416</td>
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<td>280</td>
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<tr>
<td>June 1966</td>
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<td>903</td>
<td>194</td>
<td>21.5</td>
<td>117</td>
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<tr>
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<td>10-14</td>
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<td>20.2</td>
<td>68</td>
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<tr>
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<td>1359</td>
<td>286</td>
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<td>185</td>
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<td>268</td>
<td>35.6</td>
<td>186</td>
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<td>401</td>
<td>109</td>
<td>27.1</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>5-14</td>
<td>1155</td>
<td>377</td>
<td>32.6</td>
<td>264</td>
</tr>
</tbody>
</table>

Specific gametocyte index of *P. falciparum*

1965 65/1241 = 5.2 %
1966 70/1359 = 5.1 %
1967 98/1155 = 8.4 %

Percentage of *P. falciparum* cases with gametocytes

1965 65/297 = 21 %
1966 70/195 = 35 %
1967 98/271 = 36 %
Annex III. CHANGES IN PARASITE RATES IN SNUOL

A  Expected rate of fall of parasite rate with 0 reproduction rate
B  Changes in parasite rate in age group 5-14
F  Changes in *P. falciparum* parasite rate in age group 5-14
G  Changes in *P. falciparum* gametocyte rate in age group 5-14
The purpose of the WHO/MAL series of documents is three-fold:

(a) to acquaint WHO staff, national institutes and individual research or public health workers with the changing trends of malaria research and the progress of malaria eradication by means of summaries of some relevant problems;

(b) to distribute to the groups mentioned above those field reports and other communications which are of particular interest but which would not normally be printed in any WHO publications;

(c) to make available to interested readers some papers which will eventually appear in print but which, on account of their immediate interest or importance, deserve to be known without undue delay.

It should be noted that the summaries of unpublished work often represent preliminary reports of investigations and therefore such findings are subject to possible revision at a later date.

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