Larval occurrence, oviposition behavior and biting activity of potential mosquito vectors of dengue on Samui Island, Thailand

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ABSTRACT: A 1995 outbreak of dengue haemorrhagic fever (DHF) occurred on Samui Island in Thailand with an incidence of almost 500 cases/100,000 population. To find and develop effective strategies to control this disease through cost-effective vector control programs, entomological studies were carried out on the island between 1996 and 1998. There were two species of DHF vectors, *Aedes aegypti* and *Ae. albopictus* prevailing on the island, and the population of *Ae. aegypti* remained relatively constant throughout the year while the abundance of *Ae. albopictus* increased substantially during the rainy season (May-December) and then declined drastically in the dry season (January-April). The ranges of the three *Aedes* larval indices, Breteau index (BI), house index (HI) and container index (CI) were 93-310, 43-89 and 16-50 respectively. The ceramic or earthen jars both inside and outside the dwellings and concrete water storage tanks (mostly in toilets and bathrooms) served as the main breeding places of *Ae. aegypti* whereas coconut husks and coconut floral spathes found outdoors were the major breeding sites of *Ae. albopictus*. The number of washing water jars, concrete tanks and natural sites infested with *Aedes* larvae increased significantly in rainy season, with 60% of ovitraps become positive for *Ae. albopictus* eggs with an average number of 26 eggs/trap in 3 days of setting. There was a complete lack of oviposition by *Ae. aegypti* in outdoor ovitraps (15 m away from the houses). The indoor biting rate ranged from 1.5 to 8.1 mosquitoes/man-hour, while the outdoor rate was between 5 and 78 mosquitoes/man-hour. Of the indoor biting mosquitoes, 75.4% were identified as *Ae. aegypti* and 99% of the outdoor ones were *Ae. albopictus*. The diel biting activity of *Aedes* during the period from 0800 h to 1700 h in the houses was higher in the morning than in the afternoon period, with a low prevalence between 1300 h and 1400 h. *Journal of Vector Ecology* 26 (2): 172-180. 2001.

**Keyword Index:** Dengue vectors, *Aedes aegypti*, *Aedes albopictus*, ecology, biting and oviposition.

INTRODUCTION

Samui Island is an important tourist attraction in Thailand and is visited by many foreign and local tourists. It is estimated that about 700,000 people visit this island each year. The visitors coming to the island each year amount to approximately 35 times of the local population. The tourists as well as the indigenous people suffer equally from mosquito bites and register complaints regarding mosquitoes with the local authorities. The mosquitoes that adversely affect people on Samui are primarily *Ae. albopictus* (Skuse) and *Ae. aegypti* (L.). In addition, these mosquitoes are involved in precipitating dengue outbreaks. An epidemic of DHF occurred on Samui Island in 1966 and 1967 (Winter et al. 1968) where *Ae. aegypti* and *Ae. albopictus* were abundant and widespread and dengue viruses were repeatedly isolated from both species (Gould et al. 1968, Russell et al. 1968, Russell et al. 1969). Recently, in 1995, there was another outbreak of DHF on this island when 159 cases of the disease (497 per 100,000 resident population) were reported and dengue virus was detected in both *Ae. aegypti* and *Ae. albopictus* (Thavara et al. 1996).

In southeast Asia, it has been noted that *Ae. aegypti* has spread throughout urban areas such as Bangkok, and has replaced the competing native species, *Ae. albopictus* (Rudnick and Hammon 1960). *Ae. albopictus* exhibits greater flexibility in various traits than *Ae. aegypti*, such as the choice of oviposition sites (Gould...
et al. 1968). However, the preferred breeding sites of the species are different and only slight overlap has been noted (Gould et al. 1970). In the past two decades, there has been a dramatic increase in the development of infrastructure, accommodations and facilities for tourism purposes, such as hotels, resorts or bungalows and associated services as well as residential units in various areas around the island. It is believed that these developments have had an impact on the abundance of *Aedes* mosquitoes by providing more habitats for these mosquitoes and thus leading to an increase in the abundance of dengue vectors.

To provide background information on larval occurrence, biting seasonality and oviposition behavior of adult mosquitoes, we studied the role of major developmental sites of larvae using various indices for *Aedes* larvae. We also elucidated the magnitude of oviposition of *Ae. albopictus* on the island using modified ovitraps. The overall objectives were to identify major sources of larval breeding using several indices and to elucidate the oviposition behavior of *Ae. albopictus* and biting activity of both these two important species (*Ae. aegypti* and *Ae. albopictus*). These studies were carried out on nine occasions over a period of about two years, from March 1996 to July 1998.

**MATERIALS AND METHODS**

**Study sites**

Samui Island is the largest of a group of several dozen islands in the Gulf of Thailand, located between 9° 38′ and 10° 7′ east longitude, and 9° 20′ and 9° 45′ north latitude. It is one of the districts of the Suratthani province in southern Thailand, with an area of 227 km². The island is quite mountainous with 54% of it covered with mountains. The island is divided into seven administrative subdistricts, consisting of 39 villages with a local population of 32,814, a density of 144 people/km². Normally each year, two tropical monsoons (i.e., southwest and northeast monsoon) dominate the climate of Samui Island. The onset of the first monsoon starts in May while that of the second begins in November. As a result of these monsoons, the annual average rainfall for Samui Island is over 1000 mm each year.

To carry out the proposed studies, one representative village per each of the seven subdistricts was selected. At least 50 premises (mostly residential) in each village were selected randomly to carry out the entomological surveys. In general, each village consists of a mix of residential areas, coconut plantations, fruit orchards and/or forested areas. The residential areas are of two types, residential houses and shop houses. Most of the bungalows are built in the residential areas in the villages around the island to supply economical accommodations for the tourists who would like to stay for long periods of time. Coconut palms constitute the most common landscape tree around residential and touristic structures, and the palm stands interspersed with grasses and small bushes between and around the trees. The residential areas also have small fruit orchards consisting of many kinds of fruit trees, such as rambutan, lansat, durian, mangosteen and sapodilla trees. The mountainous areas (not studied) are wooded areas and jungles. Although there is a piped water supply in most residential and commercial areas of the island, many water-storage containers are still kept in and around each house for collection and storage of rain as well as domestic water. To supplant the precarious source of domestic water supply, the local people catch and store rain water in small to large jars and tanks. Moreover, the local people prefer using rainwater to the piped water. These multitude of water storage containers provide preferred developmental sites for *Aedes* species.

**Entomological studies**

*Larval occurrence:* The entomological studies were carried out on the island during nine survey periods in March and July 1996, January, March, May, June, July 1997, and January and July 1998. We were not able to gather entomological data during the heavy monsoon season (August to December of each year) because of heavy rains and also fiscal year financial constraints at that time of the year. Populations of *Aedes* mosquito larvae were determined by visual larval survey techniques (Service 1976), and expressed as indices giving the percentage positive for each parameter. These indices were House Index (HI): the percentage of houses positive for larvae, Container Index (CI): the percentage of water-filled containers positive for larvae, and Breteau Index (BI): the number of positive containers per 100 houses. In each period of the nine occasions of the study, at least 50 houses in each of the selected village in each of the seven subdistricts were surveyed for both indoor and outdoor *Aedes* mosquito breeding places. The outdoor larval surveys were conducted within 15 m of the houses.

For species composition during one study in July 1996, mosquito larvae collected from both indoor and outdoor containers from 137 houses randomly chosen from among the seven villages were identified to species. From the larvae collected from these sources, 411 fourth-instar larvae were mounted on slides for species identification.

A separate study was also carried out in July 1996 to get information on the outdoor breeding potential of *Aedes* mosquitoes in natural sites. About one thousand
individual natural breeding sites, such as coconut husks and coconut floral spathes (both hold water) on the ground around the island were examined randomly for larval prevalence and species identification.

Outdoor oviposition: Because of scanty information on the oviposition activity of Aedes outdoors on Samui Island, we examined the breeding potential of Aedes in July 1996 in four villages of the island by using modified ovitraps of Pratt and Jacob (1967). The ovitraps used were 450 ml-capacity flower pots (9 cm high and 10.5 cm in diameter at the top) that had no drain holes. Eighty ovitraps filled with 300 ml of rain water were set 15 m away from the houses on the ground in shady areas protected from intense rain and wind. The inside of each ovitraps was lined with a strip of white filter paper for mosquito oviposition. Three days after their placement, the paper strips were collected and examined for Aedes eggs. If eggs were present, they were counted under stereomicroscope. For species compositions, the egg strips were brought to the laboratory and after conditioning for a week were hydrated and the eggs hatched. The larvae were reared to the adult stage and identified to species.

Biting activity: In order to ascertain the biting activity pattern of Aedes mosquitoes on Samui Island, two studies were carried out. In the first study, mosquito biting activity was assessed both indoors and outdoors on 9 occasions in 1996, 1997, and 1998. Human volunteers were used for collection of mosquitoes. Three volunteers captured mosquitoes indoors for 20 min, each volunteer collecting in two dwellings in each village. The three volunteers thus collected mosquitoes in six dwellings in each village and then moving to the next village. The collectors indoors usually situated themselves in dark areas of the rooms where most biting activity occurs (personal observations). The collectors bared their legs between the knee and the ankle and collected all landing and biting mosquitoes individually in vials. Similarly, three volunteers were used in outdoors collection, the volunteers stationed themselves 15 m away from the dwellings. Each outdoor collector captured mosquitoes landing or biting on their legs outside each of two houses for 20 minutes each. In total, six indoor and six outdoor captures (sites selected randomly) were made in each village. After finishing the capture and collection in one village, the volunteers moved on to another nearby village where they made similar collections in each of the seven villages. The landing-biting captures were carried out from 0800 to 12.00 h., and the collections for the total seven villages were completed in two consecutive days. Collected mosquitoes were visually identified, as there were only two species, Ae. aegypti and Ae. albopictus present. The data of all biting and landing activity for all the houses, indoors and outdoors of all seven villages were pooled and reported as biting rate of mosquitoes indoors and outdoors for each of the nine observations. To relate the extent of biting activity to rainfall, we obtained rainfall data for January 1996 to December 1998 from the Samui Meteorological Station.

In the second study, landing and biting rates were assessed one time in Mae Nam village in July 1996. The biting activity of Aedes mosquitoes was assessed indoors only using three volunteers, one in each of three houses determined to have high larval and adult populations. Each volunteer was stationed in a dwelling and collected landing-biting mosquitoes continuously on both bared legs for a 20-minute period with a 10-minute break. Thus two 20-minute collections were made by each volunteer in each house per hour. The collections were made from 0800 to 1700 h. All biting mosquitoes collected by the three volunteers in the three houses were pooled and the biting rate calculated per each hour. The collected mosquitoes were sexed (significant number of males also landed), identified and the biting rate was based on female mosquitoes only.

Data analysis

The mean number of containers positive for Aedes larvae per house in each survey was compared by one way ANOVA; if significance was observed, the mean number was then compared by Duncan’s Multiple Range Test. The number of each type of containers found positive for Aedes larvae was compared between dry and rainy season by Student’s t-test. Before analysis, the data were transformed to $\sqrt{X + 0.5}$ prior to statistical comparisons. The accepted level of significance for all comparisons was $P < 0.05$. Analysis was carried out using the SPSS program for windows version 9.0.

RESULTS

Larval occurrence

A total of 18,937 containers from 3,233 houses on Samui Island were inspected for Aedes larvae during the nine study occasions between March 1996 and July 1998. Of these containers, a total of 7,514 containers situated in and around 2,425 houses were infested with Aedes larvae. As can be seen from the data, Aedes larval prevalence as expressed by BI, was greater than 100 during the study period, except that in March 1996 it was only 93 (Table 1). The other two larval indices, HI and CI, showing percentage positive ranging from 43 to 89 and 16 to 50, respectively, for these two indices. These indices were also lowest in March 1996 as was
the case with BI. Unlike BI, the HI and CI indices were relatively constant over the entire study period.

The mean number of containers (indoors and outdoors) infested with Aedes larvae per house as shown in Figure 1 revealed a relatively stable level of larval occurrence over the study period with some fluctuations, with an especially low value at the beginning of the study in March, 1996. The average number of all types of containers positive for Aedes larvae found per house in 1996, 1997 and 1998 was 1.6, 2.3 and 3.0, respectively. The low average number in 1996 is due to the very low value obtained at the outset of the study in March 1996. The average number of positive containers per house in 1997 and 1998 was essentially the same.

It is important to note that the washing water storage jars and concrete water storage tanks (in bathrooms and toilets) were the main breeding sites of Aedes larvae inside and adjacent to the houses in both dry and rainy season (Figure 2). On the other hand, flower vases and pot saucers, drinking water storage jars, ant guards and natural sites (adjacent to houses) served as minor breeding sites during both seasons. The number of washing water storage jars, concrete tanks and natural sites infested with Aedes larvae was significantly greater in the rainy season than in the dry season (P < 0.05). In contrast, there were no significant differences in the number of infested drinking water storage jars, ant guards and flower vases & pot saucers between the dry and rainy seasons (P > 0.05).

As to the species cohabitation of larvae in water storage containers and natural sources based on 411 larvae collected from containers inside and around 137 houses, some containers had one or the other or both species (Ae. aegypti, Ae. albopictus). Among the water containers sampled, 55% were infested with Ae. aegypti alone, 35% with only Ae. albopictus, and 10% with both species. It was also found that either Ae. aegypti or Ae. albopictus or both these species cohabited with other mosquito species, such as Culex quinquefasciatus Say or Toxorhynchites splendens Wiedemann, but the latter two species occurred in very small numbers. Another important finding during the course of this study was that Ae. aegypti larvae were found only in artificial containers, whereas those of Ae. albopictus were distributed more widely in various kinds of oviposition places, both natural and artificial sites.

As far as the developmental sites of Ae. albopictus are concerned, most of the breeding potential of this species was noted to be outdoors. Of the almost 1000 outdoor natural breeding sites surveyed around the island, it was found that approximately 45% of the 623 coconut husks and 10% of 360 coconut floral spathes inspected were routinely infested with Ae. albopictus larvae.

Outdoor oviposition

To examine the outdoor breeding potential in artificial containers and natural sources, ovitrap assessment was made in outdoor premises. The oviposition activity showed that 60% of the 80 ovitraps were infested with Ae. albopictus eggs. The average number of eggs deposited on filter paper strips was 26 eggs per trap per 3 days with a range of 11 to 59. Of the eggs collected in ovitraps about 40% of the eggs hatched out on first hydration. The larvae reared to the adult stage all belonged to Ae. albopictus. These results clearly indicate that outdoor artificial and natural breeding sources provide suitable habitats for the oviposition and breeding of Ae. albopictus. There were no adult Ae. aegypti resulting from the larvae hatched from the eggs laid in the outdoor traps during this study, indicating that this species propagates in water storage containers located either indoors or just within 15 m outside the residences.

Table 1. Larval abundance indices of Aedes mosquitoes on Samui Island, Thailand, between March 1996 and July 1998.

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<tr>
<td></td>
<td>Mar</td>
<td>Jul</td>
<td>Jan</td>
</tr>
<tr>
<td>HI a</td>
<td>43</td>
<td>82</td>
<td>77</td>
</tr>
<tr>
<td>CI b</td>
<td>16</td>
<td>43</td>
<td>44</td>
</tr>
<tr>
<td>BI c</td>
<td>93</td>
<td>234</td>
<td>240</td>
</tr>
</tbody>
</table>

HI a : Percentage of houses positive for Aedes mosquito larvae.
CI b : Percentage of containers positive for Aedes mosquito larvae.
BI c : Number of containers positive for Aedes mosquito larvae per 100 houses.
Biting activity

The data of seasonal adult mosquito biting activity as shown in Figure 3 clearly indicate that the biting activity rate of indoor biting mosquitoes, comprised mostly of *Ae. aegypti* remained relatively constant throughout the nine occasions of this study. However, the population of outdoor biting mosquitoes mostly or exclusively *Ae. albopictus* usually increased dramatically in the rainy season, especially in July 1998. Over the entire study period, the indoor biting rates of *Ae. aegypti* ranged from 1.5 to 8.1 mosquitoes/man-hour, whereas the outdoor rates of *Ae. albopictus* were between 5 and 78 mosquitoes/man-hour. Although there was little or no rainfall in March 1996 and 1997 (dry season), both *Aedes* mosquitoes were still found to be biting at the study sites, *Ae. albopictus* occurring at much lower numbers than in the rainy season. It is interesting to note that even though the breeding sites of *Ae. albopictus* were severely restricted during those dry periods than those of *Ae. aegypti*, the number of adult *Ae. albopictus* was about five times greater than that of *Ae. aegypti* in March 1996, but somewhat lower than that of *Ae. aegypti* in March 1997. *Ae. aegypti* breeds in artificial containers indoors and outdoors close to the dwellings and their numbers are not affected by lack of rainfall because these containers are usually filled with tap or well water even in the dry season. The natural sites outdoors (breeding sources of *Ae. albopictus*), however, are essentially devoid of water in the dry season. In terms of spatial biting activity, the indoor biting mosquitoes were composed of 75.4% *Ae. aegypti* and 24.6% *Ae. albopictus*, while the outdoor biting adults (15 m away from the houses) were 1% *Ae. aegypti* and 99% *Ae. albopictus*. Thus, it is quite obvious that *Ae. aegypti* is primarily an endophagic mosquito, rarely biting outside while *Ae. albopictus* is primarily an exophagic mosquito but can be found in significant numbers biting indoors. From the data in Figure 3, it appears that *Ae. albopictus* exhibits much higher biting rates than *Ae. aegypti* in the rainy periods. This marked difference is the result of extensive breeding sources outdoors that become productive in the rainy season.

According to the results we have obtained on the diel biting activity of mosquitoes indoors, it was found that the biting activity of *Aedes* mosquitoes was higher in the morning hours than in the afternoon period, with a low biting activity between 1300 h and 1400 h (Figure 4), the sun usually rising at about 0600 h and setting around 1800 h in the month of July. The biting rate in the morning period was almost twice as high as that in the afternoon period. The *Aedes* mosquitoes collected in this indoor biting study were identified as 80.2% *Ae. aegypti* and 19.8% *Ae. albopictus*.

**DISCUSSION**

As demonstrated in this as well as previous studies, Samui Island is infested with both *Ae. aegypti* and *Ae. albopictus*. However, *Ae. aegypti* populations as indicated by their seasonal biting activity found here,
No. of containers positive for Aedes larvae

<table>
<thead>
<tr>
<th>Habitats</th>
<th>Dry season</th>
<th>Rainy season</th>
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<tr>
<td>Drinking water jars</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Washing water jars</td>
<td>100</td>
<td>250</td>
</tr>
<tr>
<td>Concrete tanks</td>
<td>150</td>
<td>300</td>
</tr>
<tr>
<td>Ant guards &amp; Pot saucers</td>
<td>200</td>
<td>350</td>
</tr>
<tr>
<td>Flower vases</td>
<td>250</td>
<td>400</td>
</tr>
<tr>
<td>Natural sites</td>
<td>300</td>
<td>450</td>
</tr>
</tbody>
</table>

prevail throughout the year at a relative constant level because their major breeding places are human-made water storage containers which are regularly filled with water, even during the dry season. *Ae. albopictus*, on the other hand, breeding primarily in natural developmental sites outdoors, were noted to be markedly depressed in dry seasons when the developmental sites were mostly dry. With an increasing trend of housing developments, resorts and tourist facilities and effective solid waste management that do not allow water-catching coconut husks and spathes to accumulate on the premises, it would be expected that the breeding potential for *Ae. albopictus* may decline in the future, because these new developments will lead to the elimination or reduction in natural and artificial developmental sites over time. In some highly urbanized areas of Southeast Asia such as Bangkok and Manila, because of intensive developments, *Ae. aegypti* has replaced *Ae. albopictus* (Hammon et al. 1960), while this trend has not yet materialized in Samui Island. Over three decades ago, Gould et al. (1968) pointed out that *Ae. albopictus* might be displaced by *Ae. aegypti* as has happened in high urbanized areas of Southeast Asia. At the present time it is not conceivable that Samui Island might become highly urbanized in the foreseeable future. This scenario will continue to maintain the presence of *Ae. albopictus* at least for a few decades. From this and previous studies (Gould et al. 1968, 1970), it is clear that *Ae. aegypti* and *Ae. albopictus* have coexisted and currently coexist on Samui Island. However, the overlapping of preferred breeding sources in our study (10%) was considerably higher than that found by Gould et al. (1970). Favorable conditions leading to the high density and activity of these two vectors on Samui Island are created by the long rainy season from May to December and the water use patterns of the residents. Gould et al. (1970) mentioned that the abundance of *Ae. aegypti* and *Ae. albopictus* during the epidemic of DHF in 1967 on Samui Island related directly to the amount of rainfall. With regard to the water use patterns, the islanders prefer rain and well water to piped water for their drinking and cooking purposes, and for this reason rain and well water are always stored in jars and concrete tanks, which are the most favorite breeding sites of *Ae. aegypti*. However, in these types of containers situated indoors or just outside houses, few larvae of *Ae. albopictus* were noted. As evidenced by the Breteau Index values found in this study, *Ae. aegypti* has increased since March 1996 at the beginning of the study, showing an upward trend until the end of the study in July 1998, when the index was approximately six times higher than that set by the Ministry of Public Health for the national goal (BI of *Ae. aegypti* ≤ 50) in the DHF control program. 

Figure 2. Average number (+ S.E.) of containers infested with Aedes larvae per observation according to seasons on Samui Island, Thailand. Means of the containers in dry season were computed from the four observations conducted between January and March, whereas those in rainy season were computed from the five observations carried out between May and July. Asterisks indicate significant differences of the means of each habitat between dry season and rainy season at the 0.05 level.
Figure 3. Adult index (biting rate) of *Aedes* mosquitoes in relation to rainfall on Samui Island, 1996 - 1998.

Figure 4. Daytime biting activity *Aedes* mosquitoes assessed indoors on Samui Island, July 1996.
Therefore, it is urgent to develop and implement effective control strategies against these vectors on the island. As found in our studies, over two-thirds of all infested containers were ceramic or earthen jars and concrete water storage tanks. Because of their large volume and presence of heavy larval populations, these two major types of breeding sources should be given due consideration and they should be subjected to rigorous control measures.

Although 1% temephos granular formulation (Abate SG) is usually the treatment of choice for the control of *Aedes* larvae in artificial containers, this kind of treatment in domestic potable water supplies is always rejected by the residents. Therefore, other acceptable strategies, for example, physical or biological control measures, such as larval source reduction by dwellers or the use of larvivorous predators should be encouraged as alternatives. Although the use of *Bacillus thuringiensis israelensis* (Bti) as a biological control agent against *Ae. aegypti* larvae has been carried out in Thailand, its high cost and the unacceptability of treatments to dwellers are some of the major impediments. Also, the currently available formulations of Bti are short lived and are not cost effective for use in DHF vector control.

It should be pointed out that Samui Island is one of the largest coconut plantation areas in Thailand resulting in large amounts of coconut husks strewn over the landscapes on the island. It is estimated that over one million coconut husks exist on the island at any given time. These coconut husks will eventually be burned to make charcoal for commercial purposes, but before their burning, invariably, they are kept outdoors near the houses for considerable period of time and are usually infested by *Ae. albopictus*, especially in the rainy season. These husks are considered to be one of the highly productive breeding sites for *Ae. albopictus*. On the basis of information gathered on the potential outdoor breeding sites, using ovitraps simulating natural breeding sources, approximately 60% of the ovitraps were infested with *Ae. albopictus* eggs, yielding up to 59 eggs in a trap. No *Ae. aegypti* oviposition was noted in these ovitraps set outdoors. This may be due to numerous breeding sites available for *Ae. aegypti* indoors. The coconut husks have the potential to produce a huge number of *Ae. albopictus* on the island, especially in the rainy season. On the other hand, other natural breeding sites, such as coconut floral spathes or fruit peels are also considered to provide potential natural breeding habitats for *Ae. albopictus*. These natural breeding sites are more difficult to control than artificial containers, but for disease and pest control, it will be necessary to reduce or possibly eliminate these sources of vector species. To cope with these problems, environmental management tactics and the use of ultra low volume (ULV) spraying of pyrethroid insecticides, Bti or the combination of pyrethroids and Bti (Yap et al. 1997) are some of the options for area-wide control of *Ae. albopictus* larvae in coconut husks as well as other natural breeding sites on the island. The former method (environmental management) can be economically administered by the villagers themselves under the guidance of health officers while the latter technique may be performed regularly by the health officers once a month or more often if necessary.

During our study, it was quite rare to find *Ae. aegypti* biting outdoors, constituting only 1% of the biters, while *Ae. albopictus* bit at higher frequency inside the houses (24.6%). These findings indicate that the feeding behavior of both species as found on Samui Island by Gould et al. (1968, 1970) has not changed over the years, *Ae. aegypti* is still endophagic while *Ae. albopictus* is primarily exophagic. The corresponding months to our study (January - March), the biting rates of *Ae. aegypti* and *Ae. albopictus* found by Gould et al. (1970) were 0.2-1.5 and 0.4-1 mosquitoes/man-hour, whereas those obtained in our study were 6-10 and 2.6-8.1 mosquitoes/man-hour, respectively. This marked difference leads us to believe that the numbers of both species have increased over time. It is interesting to note that in our study *Ae. albopictus* was found to be biting more indoors (24.6%) than that reported (0.1%) by Gould et al. (1970). Because of the high breeding potential and significant biting activity, *Ae. albopictus* should be considered as an important vector of DHF on Samui Island. In addition, during the morning period, especially from 0800 h to 0900 h, is the critical period for blood feeding of both *Aedes* mosquitoes. This time window is therefore a high risk period for transmission of dengue virus from mosquitoes to humans. The high biting risk period in the morning dictates use of bednets and other personal protection measures for protecting infants and children from mosquito bites.

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REFERENCES CITED


