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Ecology of malaria vectors in the Pacific *

by

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The present paper deals with the malaria vectors in Japan, Korea and the Ryukyus (*Anopheles sinensis*) ; in the Philippines (*A. minimus flavirostris*) ; and in the South Pacific (the « *A. punctulatus* » group). The information contained herein is mainly based on unpublished reports submitted to the World Health Organization and the results of investigations during the writer's field visits.

Although *Anopheles sinensis* had been regarded as the vector of malaria in Korea, it was not until 1962, after having dissected about 5.000 mosquitoes, that the first specimen was found with natural infection of sporozoites. The positive finding was supported at the same time by experimental infection. Three out of seven *sinensis* fed on a carrier with *Plasmodium vivax* were found with sporozoites twelve days after. Further dissection revealed two more sporozoite-infected *sinensis* in 1967.

A. minimus flavirostris is the main, if not the only, vector of malaria in the Philippines. Of 14.366 mosquitoes dissected by the malaria project in 1952-1954, the sporozoite rate was 0,09 %.

The « *A. punctulatus* » group is responsible for malaria transmission in the New Hebrides, Papua and New Guinea, the Solomons and West Irian. The minor vectors, such as *A. bancrofti*, *A. karwari* and *A. subpictus*, are not considered in this paper. Dissections made during 1962-1963 by the malaria project in the Solomons revealed that the sporozoite rate of *A. farauti* was 0,27 % (of 4.062 specimens dissected) ; of *A. punctulatus*, 0,36 % (of 2.730 specimens dissected) ; and of *A. koliensis*, 2,2 % (of 405 specimens dissected).

Ecology and behaviour of the above-mentioned vectors and their response to insecticide application are briefly described below.

Anopheles sinensis Wiedemann, 1828.

Breeding habitats. — It breeds in a variety of water collection, mainly rice fields.

Life cycle. — In the insectary in which a constant temperature and humidity maintained (at 28 °C and 75 %, respectively) the egg stage lasts two days, the larval stage ten, and the pupal stage two.

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Seasonal prevalence. — The occurrence of *A. sinensis* in Korea is limited to a period of six months, from May to October. The first brood emerges in early May. Its density, closely related to rice cultivation, reaches the peak in July-early August. In southern Taiwan, China, this mosquito is present throughout the year and has two peaks of prevalence in February-March and in September and October, associated with the two rice crops (CHANG *et al.*, 1950).

Hibernation. — In Korea, *sinensis* hibernates in its adult stage, starting at the end of October when the temperature is 13°-15 °C. The most favourable places for hibernation are firewood and straw in the storehouses close to the cow stables or piled up in front of the houses. A very few mosquitoes were also found under culverts. All the collected hibernating anophelines were nulliparous but had had sperms in their spermatheca. In the month of April (temperature about 19 °C) the hibernating mosquitoes start to resume their activities and were observed to bite cows out of doors even in the daytime.

Resting habits. — It is well known that *sinensis* prefers resting in cow stables. Although very few of them remain inside the house in the daytime, a considerable number rest at night on the verandah and in the rooms before and after feeding. Its daytime outdoor resting places in Korea are diverse — potato fields, cabbage gardens, water-cress plots, rice-seed beds, weeds along the sides of ditches and ponds, barley and wheat fields.

Feeding habits. — Generally, only a very small number of *sinensis* can be caught with human bait sitting inside and outside the house. The man-biting rate outdoors is higher than indoors if the house has no light. The light attracts more *sinensis* biting man. It bites man and animal soon after dusk and throughout the night, with a peak in the second quarter of the night.

Host selection. — *A. sinensis* is generally known as zoophilic species. It definitely prefers animal blood when given a free choice of selection in an experimental hut baited at the same time with cow and man. An experiment made in Korea in 1965 by releasing 70 unfed *sinensis* into a hut baited with a cow and two men, showed that 60 had bovine blood and two with human blood. However, as observed in China (CHOW, 1948) and in Korea, this mosquito had a high human blood ratio if collected from bedrooms. Of 48 specimens collected from the houses in Korea, all had human blood ; while of 217 specimens collected from the daytime outdoor resting places, all had animal blood.

Oviposition. — The number of eggs laid per female varied from 115 to 255, with an average of 150. The eggs were laid on the second to fourth night after taking a blood meal. *A. sinensis* can still lay their eggs in ricefields even when the rice plants are five feet high and very dense, but not in the water collections fully covered by *Azolla* and *Lemna* (CHOW, 1948).

Insecticide susceptibility. — The baseline value of *sinensis* in Korea was 1.5 % DDT for LC_{50}, and 4 % DDT for LC_{100} (exposed for two hours). It was reported in the Ryukyus that the larvae of this species have developed resistance to DDT (report to WHO by Major N. E. PENNINGTON of the U.S. Army Medical Centre).

Response to insecticide application. — In Korea, observations in the field and in the experimental huts and window traps showed that DDT-spraying appears to produce no irritability and no inhibition to the feeding of *sinensis* (CHEN *et al.*, 1967). Two to six weeks after spraying, a majority of the mosquitoes entering and feeding in a sprayed hut picked up a lethal dose of DDT. Although densities of *sinensis* had been greatly reduced in sprayed houses and cow stables, there was little difference in the mosquito overall density, shown by night collections with cow bait, as compared with that in unsprayed areas Its parous rate was only a little lower in the sprayed area than in the unsprayed area (66.7 % against 67.8 % observed in 1964).

Anopheles minimus flavirostris (Ludlow, 1914).

Breeding habitats. — It breeds in slow moving waters such as streams, seepages, and rivers with grassy edges.

Seasonal prevalence. — It occurs throughout the year, with the main peak in September-December and the secondary peak in June-July.

Resting habits. — It is well known that *A. minimus flavirostris* is a highly exophilic species. In the daytime it rests mainly on vegetation along stream banks. In more developed and populated areas a small number can be found in houses in the daytime. Of 103 observations with window trap attached to different existing houses in 1952-1953, only 19 *flavirostris* were collected, giving an average of 0.18 mosquito per trap per night. Of 1662 *flavirostris* collected from an experimental hut and window trap, 9 % still remained in the hut after sunrise.

Feeding habits. — This mosquito is zoophilic, feeding particularly on domestic buffalo. It was, however, reported by the malaria project that out of 122 mosquitoes collected at night in human-baited trap, 57 % had human blood ; and of 1433 mosquitoes collected outdoors, only 7 % had human blood. It feeds on man and buffalo throughout the night, but the high peak of biting man indoors was at 2300-0100 hours and that of biting buffalo outdoors at 2200-2400 hours.

Time of entry and exit. — The observations with a buffalo-baited trap undertaken in November-December 1953 showed that *flavirostris* entered soon after dusk and continued throughout the night, with a peak at 2330-0230 hours coinciding with the peak of biting. Over 50 % of the mosquitoes left the trap at 0500-0600 hours. By releasing 151 unfed *flavirostris* into a buffalo-baited trap at night, 6.6 % (all fed) left the trap within an hour after releasing but the majority (93.4 %) remained at least longer than an hour.

Gonotrophic cycle. — Of 57-freshly-fed *flavirostris* kept in the laboratory for observation, the majority (86 %) had a 48-hour cycle.

Response to insecticide application. — Since the discovery of dieldrin resistance in *flavirostris* in the Philippines (CHOW, 1959), DDT has replaced dieldrin for the anti-malaria programme. Up to date, the mosquito is still susceptible to DDT. There appears to be no technical problem in controlling this mosquito by DDT spraying if a good coverage is achieved.

The « **Anopheles punctulatus** » group.

This group consists of three species, *A. farauti* Laveran, 1902, *A. punctulatus* Dönitz, 1901, and *A. koliensis* Owen, 1945, as presently recognized. This might be a complex, and research on genetic aspect of the group is being undertaken at the Ross Institute, London School of Tropical Medicine and Hygiene.

Breeding habitats. — *A. farauti* has a wide range of breeding habitats ; it can breed in fresh or brackish water, and permanent swamps or temporary pools. *A. punctulatus* prefers sun-lit water collection such as hoof prints, borrow pits, and drains along the roadside ; its breeding sites are created when the bushes are cleared and exposed to sunlight. *A. koliensis* is found generally in temporary pools in grasslands and in pools along the edges of jungles. In the Solomons, *farauti* was found breeding in association with *punctulatus* and with *koliensis*.

Distribution. — *A. farauti* has a wide distribution in the South Pacific : the Solomons, New Hebrides, Papua and New Guinea, West Irian, the Bismarck Archipelago, the Moluccas, Australia (Northern Territory), etc. *A. punctulatus* and *A. koliensis* are found only in the Solomons, Papua and New Guinea, West Irian and the Bismarck Archi-

pelago. BELKIN (1962) mentioned that *koliensis* was found only in the north coast of Guadalcanal. Recently the malaria project in the British Solomon Islands Protectorate (BSIP) discovered this species also in Choiseul and Ngella, in addition to Guadalcanal.

Generally speaking, *farauti* is the most prevalent species and occurs mainly in coastal areas. *A. punctulatus* is less prevalent and probably limited to hilly and bush areas. It is almost entirely absent from atolls. *A. koliensis* is much restricted in its distribution, and occurs mostly in sub-coastal areas.

Life cycle. — On Guadalcanal, it was observed that only eight days are required for *farauti* and *punctulatus* to develop from egg to adult stage at 70-90 ° F.

Seasonal prevalence. — The « *punctulatus* » group occurs throughout the year. Daytime indoor collection was made regularly in the fixed catching stations on Guadalcanal by the malaria eradication pilot project (MEPP) in the BSIP during the period September 1962 to April 1963, just before the first spraying of DDT. *A. farauti* increases gradually its density and reaches a peak in March-April. This peak was observed also in the highlands of New Guinea. *A. punctulatus* has a peak in January, while *koliensis* shows a sharp rise in November.

Resting habits. — Generally, only a small number of the « punctulatus » group was found resting inside the houses in the daytime. Daytime collections from 403 houses in 19 bush and 48 coastal villages on Guadalcanal during May-July 1962 yielded 0,54 *farauti*, 0,10 *koliensis* and 0.08 *punctulatus* per house. However, in the *koliensis* areas in BSIP, this mosquito shows a strong tendency to select human houses as daytime resting places. In one instance at Haimatua on southern Guadalcanal, 203 *koliensis* were collected from one native hut of approximately 20 × 10 ft., as observed in November 1962. In other occasions, an average of 70 *koliensis* per man-hour was obtained.

As to daytime outdoor resting places, *farauti* was found among vegetation and dead leaves, in caves and ground holes, on roots of banana trees, in cement ground basins and borrow pits, and among a heap of firewood outside a house. A great number of this mosquito could be caught from outdoor resting places from time to time at Lunga, Guadalcanal, after DDT spraying. At Inakona on southern Guadalcanal, 32 female and 19 male *koliensis* were once collected resting on stones heaped as fences around the village. Artificial ground pits were tried in Guadalcanal as possible daytime outdoor resting sites, but no vector mosquitoes were collected.

A. farauti was reported resting at night on indoor surfaces for a considerable period of time before and after biting. Its favourable resting sites inside the house are walls below the level of three feet, eaves, roof and wooden post. The number of mosquitoes resting indoors at night is much greater than that in the daytime.

Feeding habits. — The « *punctulatus* » mosquitoes bite man readily indoors and outdoors throughout the night. It was observed on Guadalcanal by the MEPP in 1962-1963 that the peak of the nocturnal activities of *farauti* occurs during the second quarter of the night (21-2400 hours), both indoors and outdoors ; and that the peak of *punctulatus* was at 00-0300 hours. *A. koliensis* is probably more active after midnight ; the same was observed also by BELKIN (1962).

Routine collections with human bait sitting indoor and outdoor undertaken between 2100 and 0300 hours during the period January to April 1963 in the fixed catching stations in Guadalcanal showed that *farauti* and *punctulatus* had only a slightly higher ratio of biting man outdoors, as 52 % against 48 %.

Daytime biting of *farauti* on man and animals was also reported in many areas.

Host selection. — It is generally known that the « *punctulatus* » group has a high human blood index (BRUCE-CHWATT *et al.*, 1966). *A. koliensis* has a higher index than the other two species.

A small number of the « *punctulatus* » mosquitoes were collected from outdoor resting places (unsprayed areas) on Guadalcanal in 1962 for precipitin test. Human

blood index was 0.43 for *farauti* (42 specimens tested), 0.38 for *punctulatus* (21 specimens tested), and 0.84 for *koliensis* (19 specimens tested).

Gonotrophic cycle. — SLOOFF (1964) mentioned that in parous females the gonotrophic cycle may take two days in species of the « *punctulatus* » group, when kept under field conditions or in the laboratory at 25 °C. MACKERRAS and LEMERLE (1949, as quoted in SLOOFF, 1964) observed a cycle of three days in newly-emerged colonized *punctulatus*. SLOOFF further suggested that *koliensis* may retain mature eggs when its breeding places have temporarily dried, and concluded, based on the experiences in the laboratory, that *farauti* and *koliensis* may lay fertile eggs 5 to 26 days after ingestion of a full bloodmeal.

Parous rate. — In unsprayed areas the parous rate of *farauti* in two islands (Russel and Florida Is. in the Solomons) was 74 % (348 mosquitoes collected from all sources and dissected during 1964-66). In DDT-sprayed areas, of 2589 mosquitoes collected and dissected during 1964-67 in Koli, Guadalcanal, the overall parous rate was 73 %.

Response to insecticide application. — As summarized by CHOW (1963), the baseline data of DDT LC_{50} were 0.5 % for *farauti*, 0.3 % for *punctulatus*, and 0.4 % for *koliensis*.

Results obtained by the MEPP in the BSIP showed that *koliensis* and *punctulatus* almost disappeared after one or two cycles of DDT spraying, but there was no reduction in the outdoor resting and biting density of *farauti*.

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