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PRINCIPAL LARVAL AND ADULT HABITATS OF *ANOPHELES FARAUTI* LAV. IN THE BRITISH SOLOMON ISLANDS

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INTRODUCTION

The "sphere of influence" (1) of the *punctulatus* group of mosquitoes covers an area of the East Indian Archipelago east of the Celebes and Roma, all of the Moluccas, New Guinea, the Bismarck Archipelago, the British Solomon Islands, the New Hebrides and Northern Australia. Except for a single record from the Banggai Islands off the east coast of the Celebes, there is no invasion of members of this group of mosquitoes west of Wallace's line.

The taxonomy of the six species of anophelines known to date from the Solomon Islands is covered in the recent studies of Rozeboom and Knight (2) Belkin, Knight and Rozeboom (3), Belkin and Schlosser (4), Owen (5), Knight and Farner (6), and Belkin (7). Of the six species, some of which are reported from Bougainville, Guadalcanal and the New Georgia group of islands, only *Anopheles farauti* Lav. is the most widespread and common inhabitant of all the major islands in this group (see Fig. 1); wherever encountered, it was demonstrated to be the primary vector of malaria and filariasis.

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Entomologic surveys revealed a remarkable adaptability of the larvae of *farauti* to develop in environments distinctive to specific oceanic islands in the Australian region. Studies conducted during the dry and wet seasons indicated that within the narrow epidemiologic constellation of the British Solomon Islands ecologic problems existed which were peculiar to each of the six major and seventeen minor islands surveyed at this time. As more field experience was gained in the progressive occupation of malarious islands, entomologists quickly realized that *Anopheles farauti* Lav. gave little warning for the role to be played in its future extent in new areas on many bases occupied by Allied troops. The infiltration of this species into clearings and catchments resulting from the physical alteration of primary jungle terrain was rapid and insidious. As the establishment of northern bases of the Solomon Islands was undertaken, the pooled cooperative energies of engineers and malariologists were spent in the construction of main roads of travel, the preparation of adequate storage surfaces and the elimination of primary foci of breeding to prevent the needless dispersal of this nomad species.

LARVAL HABITATS

The ecologic "niches" enjoyed by larvae of *Anopheles farauti* Lav. are, in general, somewhat specific throughout this area. These breeding sites emphasize the repeated maxim that *anophelines exhibit a selective environmental individuality, and that representative members of the genus tend to utilize characteristic types of water*

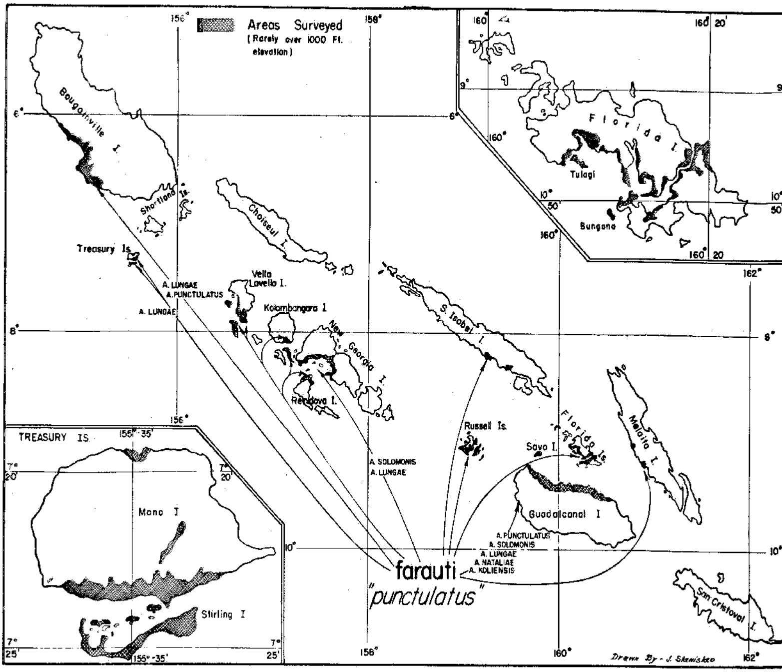


Figure 1—Map showing distribution of Anophelines and extent of areas surveyed in the British Solomon Islands.

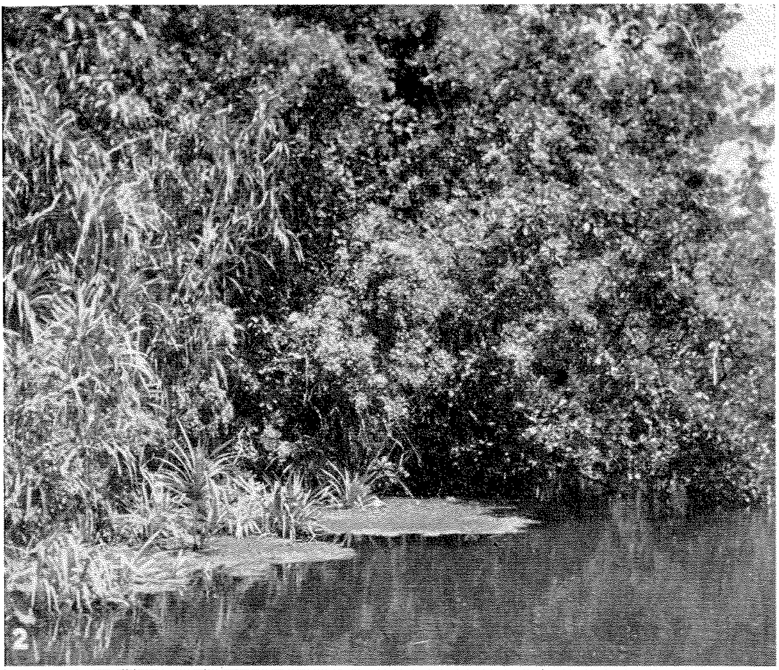
surfaces compatible for continued development and species survival.

In two years' study of *farauti* in the New Hebrides and the Solomon Islands (8,9), certain dry season habitats were reliable sources for collecting aquatic forms. Sunlit river and stream margins with protective, emergent vegetation yielded the highest larval counts. (Fig. 2) Heavily shaded streams and swiftly running, open bodies of water rarely produced larvae of *farauti* while fresh water swamps, animal wallows, and hoof prints in close proximity to native huts or villages were of localized importance. Undisturbed canebreak swamps were infrequently invaded and in many instances, until seasonal and complete biologic studies could be made, it was difficult to explain the continued absence of aquatic forms of *Anopheles* in certain swamps and ponds located within flight range of adult anopheline populations.

Records obtained from collections extending through the wet seasons were indicative of a passive transportation of aquatic forms from their confined "zones of survival" to an unselective extensive area previously known to be devoid of breeding. Thus, with prolonged periods of rainfall, specimens could be collected in varied catchments, illustrating the adaptability of *farauti* to a wide variety of water surfaces in spite of its well known selective, dry season habitats. The most productive secondary breeding sites of this

Figure 2—Sunlit river margin with emergent and floating vegetation, a breeding site of *Anopheles farauti* Lav., indicative of the selective environmental individuality of the species.

Figure 3—Road ruts, the most important man-made catchments on all occupied island bases in this area, an important stepping stone in the active migration of the species from jungle and stream margins to man's habitation.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species were created by human activities and these man-made catchments were of paramount importance wherever encountered on military bases in the occupation of the Pacific Islands. Road ruts, lumber trails, ammunition dumps, bomb and shell craters, slit trenches, road-side ditches and coral pits were classic secondary locations utilized by *farauti* for development of its aquatic forms. (Figs. 3, 4) It can generally be said, however, that the adults do not choose by preference collections of water held in factitious containers as tin cans, bottles and tire casings or in natural catchments as tree holes, leaf axils or coconut shells for the deposition of ova and subsequent development of larvae and pupae.

Guadalcanal

The long, winding, sluggish streams with marginal plant types having high anopheline production potentials provided ideal breeding areas throughout their courses in progressing seaward across the alluvial plains of the northwest coast. Outlets to many streams were blocked by sand bars formed through the pounding action of the surf and the slowly moving streams with poor gradients over-flowed their banks, thus increasing the extent of larval breeding in favorable habitats. These geomorphologic characteristics fulfilled three of the essential criteria aiding to maintain anophelines in specific areas of the South Pacific, i.e., (1) slow moving streams with adequate exposure to sunlight, (2) protective marginal vegetation, and (3) formation of lagoons and swamps at stream outlets.

During continued periods of localized heavy rainfall or frequent showers in the densely wooded, mountainous Kavo Range, eggs, larvae and pupae were not infrequently flushed from these streams, and the aquatic forms were passively dispersed over hundreds of acres of flooded, flat coastal grasslands. Rivers and streams pursuing new courses as a result of suddenly acquired pressure heads frequently cut across the winding loops in the normal course of meandering rivers and streams. With recession of flood waters and subsequent development of flood plains, many loops became isolated from the newly developed channels. Ponds were formed holding residual water and they comprised the "ox-bows" which remained as important breeding areas throughout the year.

The flat open grasslands and accessible coconut groves were repeatedly invaded by military vehicles; porous top soil became packed by vehicular traffic and numerous deep ruts were produced. These semi-permanent catchments were impervious to runoff waters and they were maintained by intermittent rainfall providing ideal conditions for the continued development of large anopheline populations.

Florida Islands

The Florida Islands presented an unusual problem relative to the control of *farauti*. Typical breeding places so well illustrated on Guadalcanal and other islands in the Solomon chain were not abundant. Prominent steep faced coral and limestone cliffs arising from the shoreline and a fine grained, buff colored, clay topsoil were natural barriers in preventing the unnecessary formation of man-made depressions and water catchments. Campsites of military forces were, therefore, limited by nature to a few hundred yards of the coastal area reducing to a minimum the extent of anopheline breeding in these principal invasion sites.

Streams flowing from seepage springs were small, yet within the widely dispersed occupied area of the Florida Islands a total of 122 main branches and prominent tributaries were mapped along the shoreline of Tulagi and Gavutu Harbors, Hutchinson Creek and Purvis Bay. Paralleling the courses of many streams, numerous semi-circular water carved "basins" were formed in the foraminiferal and conglomerate limestone. In periods of diminished rainfall and water flow, these natural basins, holding from one cup to several gallons of water, were im-

FIGURE 4—Improperly graded roadside ditch.
FIGURE 5—Limestone sink.

portant in the seasonal maintenance of anopheline populations. In sunlit areas such typical water pockets were drained by cutting v-shaped openings through the soft limestone while marginal brushing was not encouraged in the densely shaded and heavily overgrown sections of these streams.

In the Tulagi-Florida area, Kuntz (10) reported *farauti* breeding in shaded mangrove swamps with a high saline content. During periods of prolonged rainfall, numerous small streams flooded vast stretches of mangrove swamp along the coast and larvae were flushed into these exceptional water environments where they were capable of completing their aquatic development. Larvae were recovered in heavy densities from pools high in decaying organic debris.

On Tulagi, bomb and shell craters made during the initial stages of the military campaign of the Solomon Islands were of temporary importance as breeding sites. Streams on Tulagi were not large. Their courses were brief and somewhat direct with adequate drainage to the bay. In view of the rapid institution of control measures and the small size of Tulagi and surrounding satellite islands, *farauti* was readily eliminated. This successful campaign in eradicating anophelines from a well-established endemic area marked the beginning of an all-out effort throughout island-bases in the South Pacific to reduce the index of adult *farauti* in nature to a point where autochthonous malaria would not appear in unseeded troops.

Russell Islands

Numerous small streams intersecting the occupied portion of Banika Island were the most important anopheline breeding sites. During periods of diminished rainfall, water held in pot holes formed along many small streams was a prolific producer of larvae. The numerous reservoirs in these dry stream beds supported large populations of larvae and this ecologic habitat was singularly peculiar to stream beds established in the soft limestone formations of the Russell and Florida Islands.

Banika Island was characterized topographically by the presence of numerous large "swallow-holes" or "sinks." These depressions contained water throughout the year, for the levels of drainage were always the same as or below the existing water table. Thus, permanent ponds were produced, being maintained by seepage from the sub-surface water table, intermittent rainfall, and surface run-off. (Fig. 5)

Dense coatings of microscopic aquatic plants resembling the green water bloom in the United States covered the surface of many ponds. Pleuston type plant growths such as the duckweed were likewise very common. It was interesting to observe the repeated absence of mosquitoes, except for an occasional *Culex annulirostris* Skuse., breeding in ponds and fresh water swamps with such basic plant types. Only a rare anopheline was collected in what appeared to be choice breeding sites. Hess and Hall (11) indicated that microscopic plants do not produce adequate intersection lines as those formed by surface mats, leafy erects, carpet or flexuous plants. The production potential of plants promoting the development of mosquitoes appears to be directly proportional to the linear extent of the intersection between plants and any given water surface, other factors being equal. Thus, the relative intersection values of microscopic plants were not compatible for anopheline production.

Water blooms such as the red and green *Euglena* are typically found in water high in nitrogen and carbon dioxide and low in oxygen. This disturbance in acid-base balance beyond the physiologic tolerances normally acceptable to *farauti* may account for the continued absence of this species in these waters. The increase in acidity of water may rest in (1) continual dissolution of limestone by ground waters containing carbonic acids and from plants giving off carbon dioxide during photosynthesis and (2) as a result of interaction of acids formed in the decomposition of vegetable debris, plants, fruit, coconut husks and coconut fronds.

Although broken patches of duckweed providing adequate intersection lines for anophelines covered many fresh water sunlit swamps on Guadalcanal and the Russell Islands, *farauti* was rarely collected. Bradley (12) indicated that *Lemna* spp. in large quantities causes a lack of activity among chlorophyll-bearing plankton by cutting off sunlight from the water surface. In numerous ponds examined during repeated surveys, members of the *Chlorophyceae* were conspicuously absent. This reduction in food potential, a possible alteration in water chemistry, and the mechanical blanketing effect by dense mats of duckweed are offered as explanations for the continued absence of *farauti* over these water surfaces. Similar ponds, swamps and pot holes have been observed by the author to consistently fail to reveal larvae of this important disease-bearing vector throughout the New Hebrides in spite of their favorable locations near well traveled jungle trails or native villages.

Water surfaces with a predominance of *Lemna* spp. and *Euglena* spp. served as biologic indicators of unfavorable anopheline breeding environments in the Solomon Islands particularly in those ponds and swamps on islands having calcareous crusts as their superficial geologic structure.

New Georgia Group of Islands (Incl. Vella Lavella, Kolombangara, Rendova, Gizo, Ondonga and Vangunu Islands)

Extensive swamp areas surrounding Munda Point were the chief focal points of anopheline dispersal to shell holes, bomb craters and other combat-made catchments. Breeding was extremely heavy in all these man-made depressions as a result of previous occupation by Japanese forces. There were few streams bearing the importance of primary breeding areas such as those encountered on Guadalcanal. Natural breeding areas consisted mainly of shoreline springs, low-lying swamp areas and several small spring-fed streams along Lambeti Beach.

Malaria on Vella Lavella occurred locally and was minimal. Military installations were spread along 30 miles of the southeast coast with campsites restricted to less than three-fourths of a mile from the beach. Numerous streams penetrated the occupied area and one mangrove and several small fresh water swamps were the principal breeding areas. The main road of travel skirted the coast line and roadside pools were continual sources of re-infestations.

A brief reconnaissance of the Vila area of Kolombangara Island revealed *Anopheles* breeding in swamps and lagoons east of the Vila River. During the initial survey, Downs (13) observed large numbers of *farauti* breeding in wooden rice and water tubs left scattered by the Japanese throughout bivouac areas.

Treasury Islands

Typical breeding places of *farauti* on the Treasury Islands have been covered elsewhere by the author (14). Anopheline breeding was limited primarily to sunlit margins of heavily overgrown Soala Lake and stream on Stirling Island. Prompt control of these two sites prior to extensive military occupation resulted in complete eradication of this species from the island. Stirling Island remained anopheline-free for nearly eighteen months. Anophelines were found on nearby Mono Island along the margins of flattened small coastal streams which flowed into Blanche Harbor.

Bougainville

The area under survey on the island of Bougainville was limited to a perimeter of approximately twenty miles along Empress Augusta Bay. The extent of entomologic surveys was limited to five miles inland and these surveys were rarely conducted at elevations over 1000 feet above sea-level. Principal breeding areas at the time of occupation were along margins of several large streams flowing through sandy terraces of the island. Fresh water swamps and marshes were formed in abundance adjacent to and paralleling the seashore.

Four factors contributed to the formation of these important breeding areas, each of which was amplified due to the geographic features of Bougainville. These were: (1) excessive monthly rainfall, (2) high water table in a porous, volcanic, sandy topsoil, (3) as meandering streams approached the coast, the land became flatter and poorly drained and streams overflowed their banks for considerable distances along their course and (4) the continual, forceful, pounding action of the surf threw up sand bars at the mouths of rivers and streams. This natural blockage produced extensive impounded, shoreline bodies of water free from active tidal action and favorable for the development of *farauti*.

Densely packed algal mats formed floating carpets over much of the exposed fresh water coastal lagoons. Although such floating mats had low production potentials, they were important in extending the anopheline breeding areas into deeper water of these shoreline lagoons beyond zones of marginal vegetation.

The high water table rapidly filled all vehicle-made depressions and man-made foxholes. *Anopheles farauti* Lav. invaded in large numbers such ideal secondary sites and this invasion typified its furtiveness in occupying *in natura* secondary catchments through alteration of surface terrain and vegetative canopies by man.

Adult Habitats

Adult female *Anopheles farauti* Lav. appears to be essentially anthropophilic. Collections of this species have rarely been made from sites removed from native villages and huts, or bed-nets and quarters of military personnel. (Fig. 6)

The exact micro-climatic specifications required by this species were not determined. In only several instances have resting adult mosquitoes been collected in nature. The common denominator appears to be living quarters of human inhabitants. There exists a further selective preference in native huts within a single village. Those permanently occupied were excellent catching stations; those abandoned were likewise given up by female adults of *farauti*.

The hours of greatest activity depended to a great extent upon prevailing climatic conditions. After rains and on quiet evenings the adult anophelines were particularly active between the hours of 1700 and 2000.

A study of the active dispersal by flight of this species would indicate that it does not fly great distances over open bodies of water and it does not actively fly over unfavorable topographic or vertical bar-

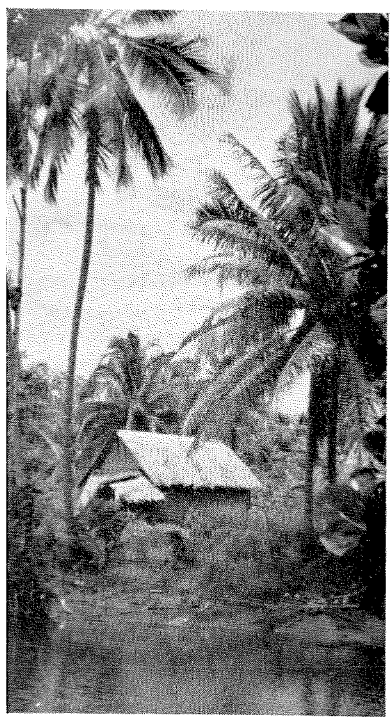

Figure 6—Native hut, an important daytime resting place of *farauti* throughout the British Solomon Islands.

riers such as dense jungle forests, mountains, or the inter-island anchorage channels in the Pacific(15). The maximum efficient flight range, i.e., the distance *farauti* will fly from breeding places in search of a human blood source, is probably not over 800 – 1000 yards. Surveys of small off-shore islands less than one-half mile from heavy anopheline production sites repeatedly and consistently failed to reveal anophelines.

In view of its anthropophilic nature, *farauti* remains the single, paramount vector of malaria and filariasis. The excellent studies on filariasis in the Solomon Islands by Byrd(16) and Schlosser(17, 18) have indicated the importance of mosquitoes other than *Culex quinquefasciatus* Say to act as vectors of this pathogenic filaria. The role *quinquefasciatus* plays in the transmission of filariasis has been demonstrated to be of little importance or secondary to other species in all areas surveyed from the Samoan Defense, through the New Hebrides and including the Solomon Islands. *Anopheles farauti* Lav. showed a 52 per cent infection rate for *Wuchereria bancrofti* on Guadalcanal. *Anopheles koliensis* may also be considered an important localized vector in nature for of 231 blooded anophelines collected on Guadalcanal, 6.9 per cent harbored various developmental stages of *bancrofti*, and 3 per cent of the total harbored infective stage larvae.

The intimate relation of *farauti* to malaria can be traced through all islands where the disease is known to exist. Although the propensity of *farauti* for human habitations is not as great as that of such strongly anthropophilic species of *Anopheles* as *gambiae, farauti* showed a high susceptibility to infection with malaria in the New Hebrides. Wherever this single species was encountered throughout the New Hebrides and Solomon Islands, malaria was reported in the indigenous population, and high rates of primary infections were reported in unseeded American and Allied combat and support troops.

Summary

(1) Six species of *Anopheles* are known from the British Solomon Islands. *Anopheles farauti* Lav. appears to be the primary vector of malaria and filariasis.

(2) During the dry season, aquatic forms are found typically along margins of sun-lit rivers and streams. The most productive man-made breeding areas were: Road ruts, bomb and shell craters, road-side ditches, and logging areas.

(3) During the wet season, eggs, larvae, and pupae were flushed from their well-known habitats and they could be found over a wide variety of water surfaces. In general, water held in tin cans, tree holes, coconut husks and other small receptacles were not favorable for the development of *farauti*.

(4) The topographic features of the oceanic islands in the Australian region greatly limited the extent of larval development and these features provided characteristic ecologic habitats on many of the major island groups in the British Solomon Islands.

(5) The adult females of *farauti* are markedly anthropophilic, and they are readily collected resting in native huts and in bed nets and quarters of military personnel.

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