148 *Transactions of the Royal Society of New Zealand*
Vol. 76, Part 2, pp. 148–157, 2 Graphs.

Observations on *Anopheles punctulatus* Dönitz, 1901, and *Anopheles farauti* Laveran, 1902*, at Palmalmal and Manginuna, New Britain, during July and August, 1945.

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[*Received by Editor, April 9, 1946.*]

Issued separately as Bulletin No. 2, Royal New Zealand Air Force Entomological Surveys, South-West Pacific, 1945. Authorised by Chief of Air Staff.

THE work discussed in this paper was commenced in the middle of 1945 during a mosquito survey of the then newly-established Royal New Zealand Air Force Station at Jacquinot Bay, New Britain.

At this time military construction work was proceeding about Palmalmal, a coconut plantation on the southern shore of Jacquinot Bay. The R.N.Z.A.F. camp was located in the south-eastern part of this plantation. Permanent pools with a balanced fauna and flora already existed in the lower-lying parts of this area. These were now supplemented with a host of man-made temporary rain pools. Freshly-dug coral pits, roadside ditches, and an abundance of ruts made by wheeled traffic and heavy caterpillar equipment were evident everywhere. As their bottom soil became compressed and impervious, these depressions filled with rainwater. *Anopheles punctulatus* Dönitz, 1901, showed a marked habitat preference for the resultant temporary rain pools. This species was generally found in small newly-formed pools that were devoid of macroflora and macrofauna and exposed to the maximum amount of sunlight.

Longer-established pools had available shade and shelter supplied by algae and emergent and overhanging grasses. *Anopheles farauti* Laveran, 1902, almost always used pools of this description as breeding places, and was rarely found in unshaded temporary pools without macroflora.

A similar difference between the habits of these two species has been noted at Rabaul (Heydon, 1923) and in various other localities in the Territory of New Guinea (Lee and Woodhill, 1944).

Table 1 lists the different types of breeding place in which developmental stages of *A. punctulatus* and *A. farauti* were found during

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* This species has previously been referred to by Australasian authors as *Anopheles punctulatus* subspecies *moluccensis* (Swellengrebel and Swellengrebel de Graaf, 1920). In their revision of the *punctulatus* complex of the genus *Anopheles*, Rozeboom and Knight (1946) show that the name *moluccensis* must become a synonym of *farauti* Laveran, 1902; and that *A. punctulatus* and *A. farauti* should be considered as systematically distinct.

this investigation, together with the number of times each species was collected. This table shows that exposed ground pools without vegetation made up 90 per cent. of the total number of breeding places in which *A. punctulatus* was recorded; while only 16 per cent. of the total number of breeding places of *A. farauti* were pools of this description.

The heaviest breeding of both of these anophelines went on in the vicinity of two villages on the coast of Cape Cunningham, just south of Jacquinot Bay. This area will be referred to as Manginuna, the name of one of the villages just mentioned. Blood smears were taken from native children at both villages. Of those smears made at an administration hospital 33 per cent. were positive for malaria. As spleen enlargements were not taken into account and the population here was constantly changing and not actually representative of the coastal people, this figure failed to give a true indication of the local incidence of malaria. Only seven children from one to three years of age could be examined at Manginuna village itself. The blood of all seven held malaria parasites. *Plasmodium vivax, P. falciparum* and *P. malariae* were all found in these examinations, and there were several mixed infections.

The work of de Rook in Dutch New Guinea (de Rook, 1926, in Swellengrebel and Rodenwaldt, 1932) and of other investigators (notably Aberdeen at Milne Bay, Papua; and Heydon at Cairns, North Queensland, and Rabaul, New Britain; in Lee and Woodhill, 1944) had proven both *A. punctulatus* and *A. farauti* to be malaria vectors. Thus the villages at Manginuna provided a reservoir of malarial infection for the anophelines constantly emerging in their vicinity.

Although this area was within half a mile of the R.N.Z.A.F. Station outskirts, it was not subject to malaria control during the earlier stages of occupation. Both station and airstrip were built on a ridge parallel with the coast and at an altitude of 200 ft. The heavy rain forest that covered half a mile of rising ground between Manginuna and the nearest part of the R.N.Z.A.F. area was thought at first to be an effective barrier to the flight of anophelines from the coast.

Several men belonging to a servicing unit situated over a mile distant from the main station sleeping quarters and half a mile away from Manginuna, were hospitalized with either M.T. or B.T. malaria in August. It was demonstrated that these men had been working in the evening or spending the night at their section from nine days to a fortnight before symptoms of malaria became apparent. They admitted that they had not been taking their daily atebrine issue.

These infections could not be attributed to anopheline breeding within the station bounds. On the landward side of the ridge on which the station stood, a jungle-covered hillside sloped down into the heavily wooded valley of the Kalumalagi River. No anopheline breeding places were discovered in this valley, where sunlight did not reach the swampy forest floor. There were no permanent water bodies on top of the station ridge, although numerous artificial pools were formed as a result of camp construction activities. Until the main tasks of building the camp and trucking stores had been completed, potential breeding areas on this ridge were kept extremely muddy by a combination of intermittent torrential rain and heavy vehicular traffic. The pools concerned were thus rendered temporarily unsuitable for anopheline development. Many of these pools were left comparatively undisturbed after the rate of construction work slowed down, and anopheline breeding then began in them. Such potential danger spots within station bounds were kept under constant entomological supervision, and the malaria control section dealt with fresh breeding as it became apparent.

Evening collections were made inside buildings at the servicing section. These collections resulted in the capture of a few engorged imagines of both *A. punctulatus* and *A. farauti.* The wings of these mosquitoes were in an almost threadbare state. Besides indicating that the anophelines secured were probably old (Perry, 1912), this fact suggested that the insects concerned might have travelled some distance. Had breeding been going on near at hand, some young individuals with undamaged wings would have been expected to be present.

Meteorological reports showed that at the time the men concerned became infected with *Plasmodium* (that is to say, about ten days before symptoms of malaria appeared) there had been unusually strong evening breezes. South or south-easterly winds reaching gale force at times had blown directly towards the station from the direction of the breeding places at Manginuna.

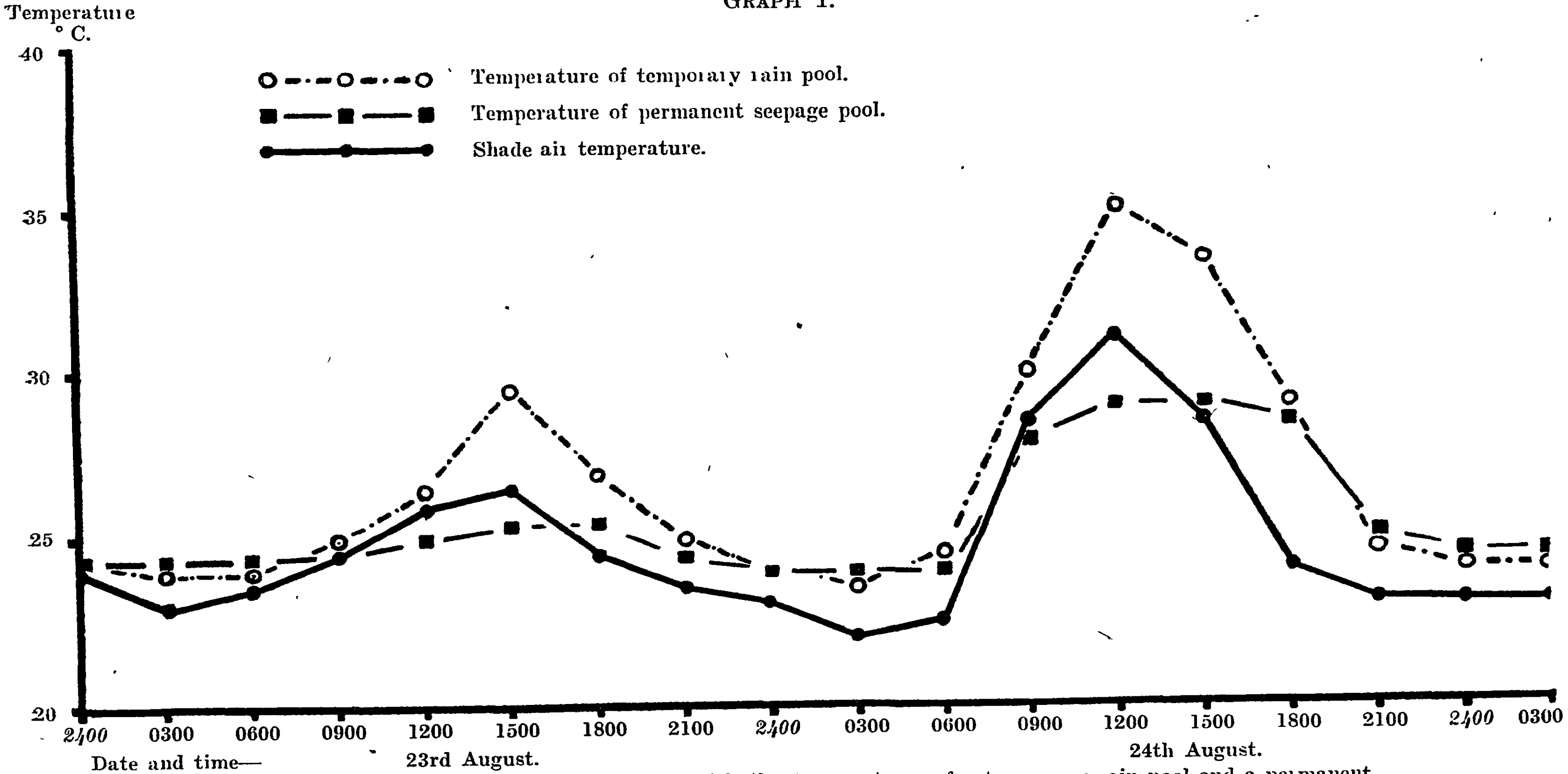
From the beginning of September the Manginuna area was subjected to malaria control. Thereafter, anopheline breeding pools in this vicinity were sprayed each week with 5 per cent. D.D.T. in Diesel oil. Extra attention was paid to the area in dry periods following heavy rainfall. In the following months only three more cases of malaria were reported from the station.

The indirect evidence outlined above suggests that anophelines were blown from the blood-meal source immediately available at their breeding grounds at Manginuna; and that the winds responsible carried them over or through half a mile of rain forest to the R.N.Z.A.F. area.

It has already been indicated that *A. punctulatus* showed a habitat preference for temporary pools of recent origin at Jacquinot Bay. Collections made in adjacent undisturbed coastal areas rarely resulted in the capture of this species. *A. farauti,* on the other hand, was usually found breeding in various types of long-established water bodies. The latter mosquito was collected from permanent pools in all the undisturbed coastal areas visited, and formed a significant part of the natural culicine community. Grading and milling operations about Palmalmal and Manginuna tended to decrease the number of long-established pools available to *A. farauti.* At the same time, many fresh pools suited to the breeding requirements of *A. punctulatus* were formed on the exposed ground resulting from this clearing and construction work. Thus during the survey under discussion *A. farauti* was much less commonly collected in this vicinity than *A. punctulatus.*

A series of field observations was made to gain an insight into the environmental factors influencing the development of these two

GRAPH 1.



A comparison of the shade air temperatures with the temperatures of a temporary rain pool and a permanent seepage pool at Manginuna, New Britain, 23rd and 24th August, 1945.

anophelines. The investigations were carried out at Manginuna during July and August, before malaria control was extended to this area. Daily larval counts made at a typical breeding place of each species were correlated with routine rainfall measurements made by the R.A.A.F. and R.N.Z.A.F. meteorological sections.

The pool selected for observations on *A. punctulatus* was in a wheel-rut on gently sloping bare ground. This rut measured 8ft. 6 in. by 1 ft. 3 in., and the maximum depth of the contained water was 5 in. The breeding place was exposed to full sunlight throughout the day. It had no macroflora, and apart from batches of *Culex pullus* and *A. punctulatus* itself, developmental stages of Chironomidae formed the only macrofauna.

A seepage pool in a grassy clearing at the edge of nearby jungle was chosen as a typical breeding place of *A. farauti*. The pool stretched for 30 ft. along the base of a low cliff and averaged 10 ft. in breadth and about 12 in. in depth. There was direct sunlight available for most of the day. Thick grass that bordered this permanent pool provided mosquito larvae with shade, also with some shelter from predacious insects. Among such predators dragonfly nymphs (particularly Zygoptera), water boatmen, and whirligig beetles readily fed on mosquito larvae and, to a lesser extent, on the pupae.

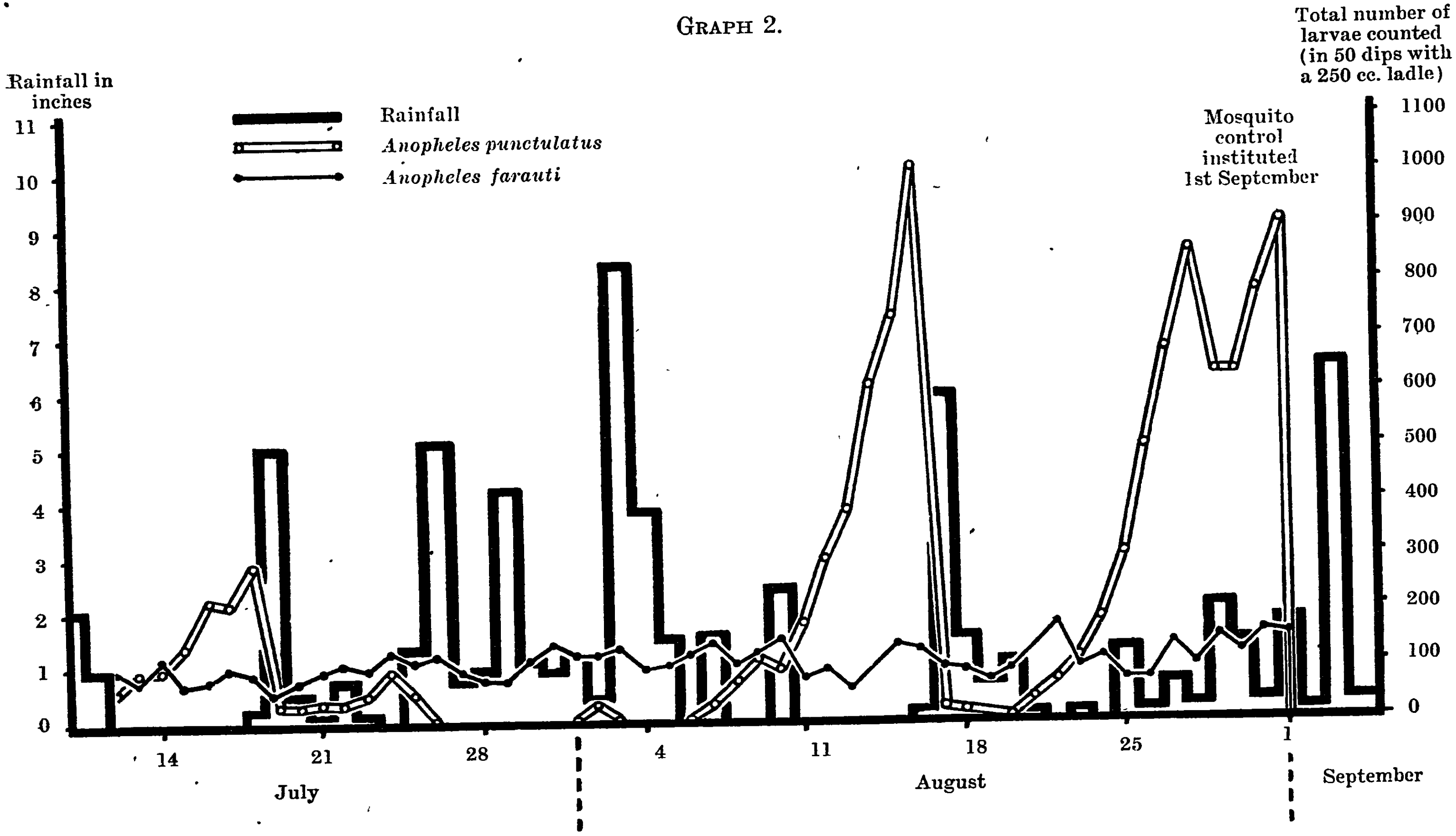
The water in both pools was usually quite clear. Coral mud stirred up by rain in the small temporary pool soon settled again. The hydrogen-ion content of rain water in the wheel rut averaged pH 6·0, and that of seepage water in the larger pool pH 6·5. In this connection it should be noted that both anophelines were found elsewhere in waters of which the hydrogen-ion content varied from pH 5·5 to pH 8·0.

A series of readings showed that the small exposed pool was subject to a greater temperature range than the other.

An analysis of readings taken at three-hourly intervals on two consecutive days is given in Graph 1. It will be seen that at the height of the day the temperature of the temporary rain pool was considerably above that of the permanent pool, and also higher than the air temperature; while that of the latter pool was below air temperature. At night time the permanent pool was very slightly warmer than the other, and both pools were above air temperature. During July and August the highest temperatures recorded from the small exposed pool and the seepage pool respectively were 41° C. and 32° C. Laboratory experiments on the extremes of heat tolerance of *A. punctulatus* and *A. farauti* were not carried out, because of a lack of thermostatic apparatus.

Daily larval counts were made at 1 p.m. in the temporary rain pool and at 1.30 p.m. in the other. Before making a count the water was muddied by vigorous stirring. This agitation tended to break up any uneven distribution of larvae, and gave a fairly uniform spreading of the developmental forms present over the water surface. Larval instars were not differentiated in the count, which was the sum total of larvae collected in 50 dips made at random along the surface of the water with a 250 cc. ladle. Pupae were not taken into consideration, because of the possibility of their being confused with pupae of

GRAPH 2.



The relationship between rainfall and the larval populations of *Anopheles punctulatus* Dönitz in a temporary rain pool, and *Anopheles farauti* Laveran in a permanent seepage pool, at Manginuna, New Britain, during July and August, 1945.

other genera in the limited time available for field examination. The yield from each dip was transferred to a container for return to the pool on completion of the observation.

Graph 2 shows the relationship between rainfall and the larval abundance of *A. punctulatus* and *A. farauti* as determined from the daily counts. It will be seen that few larvae were present in the temporary rain pool during the last week of July and the first week of August. A few early instars were collected on 2nd August, but none could be found on the following day. Over this period of two weeks heavy showers of rain frequently flushed out the pool and prevented *A. punctulatus* from becoming established in it. Spells of comparatively dry weather occurred from 12th–18th July, 6th–16th August, and 21st–31st August. During these three spells, which each followed particularly heavy rain, the temporary rain pool was not subjected to severe flushing. Larvae of *A. punctulatus* rapidly became abundant in this pool during each of these comparatively dry periods. At the same time some smaller breeding places nearby became quite dry, before the larvae they contained had undergone metamorphosis.

The time required for the development of *A. punctulatus* from egg to adult was found to vary between 6½ and 9 days (Laird, 1946). Heydon (1923) mentioned that the average duration of the larval stage of this species (which he referred to as the "D. variety") was somewhat shorter than that of *A. farauti* (the "*moluccensis* variety"). He stated that "the shortest period from oviposition to imago observed with certainty in this variety was nine days, but it is doubtful if this is the minimum," and pointed out the advantage of such a short aquatic life cycle to a mosquito using breeding places of a temporary nature.

Heavy downpours on 19th July and 17th August flushed out the temporary rain pool. In each case only a few survivors remained of the large population built up in the preceding dry spell. On 10th and 29th August there were slight decreases in the numbers of larvae present, in response to showers not heavy enough to completely flush out the pool. The daily counts were discontinued at the end of August, because of the extension of malaria control to Manginuna.

Further reference to Graph 2 will show that rainfall had not nearly so marked an effect on the numbers of *A. farauti* in the seepage pool. Being situated in a natural depression, this breeding place was increased in area, but not flushed out, by heavy rains. Thus fluctuations in the *A. farauti* line in this graph may be largely ascribed to the scattering of larvae within the pool, when its perimeter was temporarily increased following rainfall.

The *A. farauti* population remained at a reasonably established level throughout, as will be seen from Graph 2. This level was very much lower than that attained by *A. punctulatus* in the temporary rain pool, during periods of dry weather. The aquatic part of the life-history of *A. farauti* was completed in 9 to 14 days under laboratory conditions, the larval stage averaging 10 days and the pupal stage 1½ days (Laird, 1946). A significant degree of biological control was undoubtedly exercised over *A. farauti* by the predacious insects associated with this mosquito in the seepage pool. Both field observations and laboratory experiments were conducted to gain an insight into the effects of these predators on the mosquito population; the results of these investigations will be discussed in a later paper. It is worthy of note that although the temporary rain pool lacked a predacious macrofauna, *A. punctulatus* displayed cannibalistic tendencies when its breeding place became densely populated. In these circumstances newly-emerged larvae of the last-named anopheline were seen to be devoured by older larvae of their own species in both field and laboratory (Laird, 1946).

A number of breeding places of *A. punctulatus* about Manginuna were not flushed out by heavy rains. For the most part, such breeding places were pools in coral pits and wheel ruts in natural hollows. These pools when left undisturbed soon acquired the biological characteristics of permanent water bodies in undrained natural depressions. They thus tended to become more suited to the breeding requirements of *A. farauti* than of *A. punctulatus.*

On the other hand, there were breeding places of *A. farauti* that were subject to a measure of flushing. Natural pools in the near vicinity of streams, shaded artificial pools in blocked drainage ditches, and wheel ruts on grassy slopes were in this category.

The field work undertaken at Jacquinot Bay indicated that exposure to sunlight and the absence of shading grasses, algae, and a predacious macrofauna, were significant criteria in determining the suitability of a pool for the breeding of *A. punctulatus.* In turn, the absence of the last three factors suggested the recent origin of the pool concerned. There was an abundance of such pools in the vicinity of Palmalmal and Manginuna; being formed by chance as a result of military activity, a great number of them bore no relation to the natural drainage pattern of the area. It was therefore concluded from the investigations discussed earlier that the flushing effect of heavy showers formed an important natural check on the population growth-rate of anopheline mosquitoes breeding in temporary rain pools. *A. punctulatus* was found to show a marked habitat preference for such pools. Thus there was a tendency within limits for larval populations of this mosquito to vary inversely as the rainfall in the Jacquinot Bay area of New Britain. A similar tendency has been reported from the wet zone of Ceylon, where sunlit pools in river beds are a favourite breeding place of *Anopheles culicifacies* Giles; the monsoon rains cause repeated flushing of these pools in normal seasons, but in years of drought rivers are replaced by series of pools in which very heavy breeding of *A. culicifacies* occurs (Gill, 1935).

As has been indicated earlier, the time required for the development of *A. punctulatus* from egg to adult averaged just over a week at Manginuna. It follows that the adult population of this anopheline increased towards maxima from upwards of a week after the close of rainy periods; and decreased towards minima as a result of prolonged heavy rain hindering larval development.

Any increase in the flying population of *A. punctulatus* means an increase in the number of potential malaria vectors in the area concerned. We may safely assume that in a malarious region where gametocyte carriers are readily available to the anophelines as at Manginuna, such a population rise is accompanied by an increase in the number of actual vectors present. A time lag of approximately three weeks must be allowed for this development (Taylor, 1944). This interval gives time for a significant increase in the flying population of *A. punctulatus* and allows for the completion of the sexual cycle of *Plasmodium* within the bodies of infected insects.

Manginuna was the only important reservoir of malarial infection in the neighbourhood of troop concentrations in this part of New Britain that was for a time not under malaria control. In general, the living quarters of uninfected personnel were too far from this area for anophelines originating here to constitute a serious hazard; although as has been mentioned, Manginuna was finally placed under malaria control in consequence of the appearance of some cases of malaria in the outskirts of the R.N.Z.A.F. Station half a mile from the coast.

If similar breeding of *A. punctulatus* were allowed to proceed unchecked in close proximity to numbers of individuals unable to take adequate measures for personal protection from the attacks of anophelines, an increase in malaria vectors would be reflected by a local increase in malaria incidence. Thus an epidemic of *A. punctulatus* was associated with a wave of malaria among Australian troops during the campaign at Milne Bay, Papua; but when anti-malarial measures were able to be undertaken, this anopheline virtually disappeared from the controlled area and the malaria outbreak waned (Lee and Woodhill, 1944).

The absence of battle conditions made it possible to enforce anti-malaria discipline and mosquito control from the outset at Jacquinot Bay. Thus there was no outbreak of malaria here comparable with that experienced at Milne Bay, where battle conditions enormously complicated the problems of malaria control.

Nevertheless, the population increase of *A. punctulatus* at Jacquinot Bay paralleled that at Milne Bay, Papua. This increase was consequent on the wholesale manufacture of suitable breeding places for *A. punctulatus* as a result of camp construction activities, and was characterised by heavy breeding of the anopheline at Manginuna before this area was subjected to mosquito control.

Heydon (1923) stated that "probably the *moluccensis* variety (*A. farauti*) is the predominant one in New Britain along the coastal strip, especially where swamps exist, while the other (*A. punctulatus*) is relatively more numerous on higher land and perhaps also in the wet season." *A. farauti,* owing to its preference for long-established breeding places, was the dominant anopheline in undisturbed coastal areas in the vicinity of Jacquinot Bay. However, clearing and settling operations produced circumstances favourable to the temporary dominance of *A. punctulatus* under the rainfall conditions discussed earlier. It thus appears likely that in normal circumstances *A. farauti* may be of greater local significance than *A. punctulatus* as a vector of *Plasmodium*; but that this position may be reversed during large-scale settling or construction projects in Jacquinot Bay and similar coastal areas of New Britain.

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TABLE I.

Collection records of *Anopheles punctulatus* Dönitz and *Anopheles farauti* Laveran at Palmalmal and Manginuna, New Britain, July and August, 1945.

NATURE OF BREEDING PLACE.	GROUND POOLS.											OTHER BREEDING PLACES		TOTAL
	Exposed and without vegetation.			Partly shaded and with vegetation.								Shaded and without vegetation.		
	Footprints in muddy ground.	Wheel ruts in muddy ground.	Coral pits, ditches, etc.	Wheel ruts, footprints, etc.	Coral pits, ditches, etc.	Native wells.	Seepage pools.	Swamps.	Stream backwaters.	Pig wallows.	Brackish pools.	Tin cans, etc.	Tree rot-holes.	
Number of breeding places of *A. punctulatus* located.	14	57	7	5	2	1	1	0	0	0	0	0	0	87
Percentage of total	16	66	8	6	2	1	1	0	0	0	0	0	0	100
Number of breeding places of *A. farauti* located.	0	7	3	22	9	3	6	5	2	1	2	4	1	65
Percentage of total	0	11	5	34	14	5	9	8	3	1	3	6	1	100