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ROYAL SOCIETY OF NEW ZEALAND

BULLETIN No. 6

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AND  
FRESH WATER ECOLOGY  
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PUBLISHED BY THE ROYAL SOCIETY OF NEW ZEALAND,  
VICTORIA UNIVERSITY COLLEGE, P.O. Box 196,  
WELLINGTON, NEW ZEALAND

January, 1956.

LONDON AGENT:  
High Commissioner for New Zealand, 415 Strand, London, W.C.2.

Printed by Otago Daily Times and Witness Newspapers Co., Ltd.,  
Dunedin, New Zealand.

## PREFACE

The field work on which this paper is based was undertaken in Queensland, the Solomons, the New Hebrides, New Caledonia and the Loyalties, Fiji, Tonga, Western Samoa and representative islands of the Cook, Gilbert, Ellice and Tokelau Groups. Data are presented for 372 collections which included mosquito larvae and for a further 85 which did not, and comparisons are made between anopheline larval habitats in the malarious zone and similar habitats in the anopheline-free zone east and south of Aneityum, New Hebrides. A new classification of the various types of larval habitats, lending itself to the study of trends in mosquito biology, is proposed. The utilization of these habitats by the various groups of aquatic animals and plants is discussed with particular reference to the diminishing representation of diversified groups of organisms with increasing longitudinal distance eastwards; and the distribution and bionomics of these organisms are considered in relation to mosquito larval ecology.

Two new fungal parasites of mosquitoes are described, *Coccomyces volomoris* n.sp. from *Anopheles punctulatus* (Dönnitz) in Guadalcanal (Solomons) and *C. cairnsensis* n.sp. from *An. farauti* Laveran in Queensland. Other organisms were found associated with mosquito larvae as follows, the host- and locality records being new. ECTOPHYTA. Bacteria—*Sphaerotilus* aff. *dichotomus* (Cohn) from *An. farauti*, Espiritu Santo (New Hebrides) and *Bironella hollandi* Taylor, *Utratotenia ciliikii* Belkin and *Culex putus* Theobald, Guadalcanal. Algae—*Characium* aff. *saccatum* Pilarszky from *An. farauti*, E. Santo, and *C. annulatris* Skuja, E. Santo and Guadalcanal. ECTOZOVA. Protozoa/Mastigophora—*Codonocea* aff. *ascocians* from *C. pulius*, Guadalcanal. Protozoa/Ciliata, *Zoothamnium* sp. from *C. ornulirostris*, Rennell (Solomons); *Vorticella microstoma* Ehrenberg and *Epistyliis lacustris* Imhoff from numerous hosts from Queensland to Aitutaki (Cook Islands); *Vorticella camporum* Ehrenberg from *C. ornulirostris* Theobald, *C. pulius* and *C. pipiens latipes* Wiedemann, Guadalcanal; *Vorticella* sp. from *An. farauti*, Guadalcanal. Rotatoria. *Habrotocha tridens* Miller from *Tripteroidea purpurea* Edwards, Viti Levu (Fiji); *Monostyla* sp. from *An. farauti*, Aneityum (New Hebrides); *Brachionus dimidiatus* (Bryce), *B. quadridentatus* Heinmann and *Habrotocha* sp. from *An. farauti*, E. Santo. ENDOPHYTA. Fungi—*Coccomyces stegomyiae* Keelin from *Aedes a. scutellaris* (Walker), Rennell; *Coccomyces*, *indianae* Iyengar from *Aedomyia catalinata* Knab, Queensland. ENDOZOVA. Protozoa/Mastigophora—*Crithidia fasciculata* Leger from *An. farauti*, E. Santo and Guadalcanal. Protozoa/Sporozoa—Undetermined ecdonitic gregarine from *An. punctulatus*, Guadalcanal; *Thelohania opacita* Kubo from *C. ornulirostris*, E. Santo. Nematoda. *Aganomeitis* sp. from *An. acutifrons* Walker, Queensland.

It is concluded that the continued absence of anophelines from certain islands of the malarious zone such as Bellona (Solomons) and Tutuba (New Hebrides), and from the perimeter islands of Futuna (New Hebrides), Ait (Blep Group) and Uvea (Loyalties) is understandable on biological and other grounds. These grounds, which are discussed in detail, differ for each individual island involved but agree in presenting ecological barriers to anopheline introductions. It is submitted, however, that no barriers of this nature are operating to prevent such introductions into the general region east of Buxton's Line, and that should *Anopheles farauti* ever penetrate into Fiji and tropical Polynesia it would find its whole range of accustomed larval and adult habitats. Attention is drawn to the probability that the current extension of S.E. Asian fish pond techniques to the South Pacific will cause increases in mosquito rates, through the wholesale creation of new larval habitats, particularly if the ponds are also used for the cultivation of aquatic food and fodder plants. New and highly suitable breeding conditions will also be established for any anophelines which may be introduced, notably *An. farauti* and—in the case of brackish fishponds—the dangerous Indo-Malayan *An. sundanus*.

The desirability of maintaining the efficiency of airport and seaport insect controls at as high a level as possible, in order to guard against anopheline introductions into the malaria-free region of the Pacific, is self-evident. At the same time, it is urged that the South Pacific affords ideal opportunities for research into the currently neglected field of mosquito control through biological agencies. Certain larval predators which do not occur in this region and which are harmless from both medical and economic viewpoints—tropical *Corethrinae* (Culicidae), hemipterans of the genera *Sphaeroforma* (Belostomatidae) and *Cercometus* (Nepidae) and even *Hydra* spp.—might be introduced with advantage, as might larval strains of such mosquito parasites as Microsporidia (Protozoa), *Aganomeitis* (Nematoda) and *Coccomyces* fungi. Other organisms which have a biological control potential are discussed, among them the indigenous Fijian eleotrid fish *Lairdina leptocephalus* Fowler which could well prove more useful under Pacific conditions than introduced fishes of the genera *Gambusia* and *Lebiasina*.

A pilot project to investigate the possibilities of employing *Coelomomyces* as a biological control agent could be carried out under ideal conditions in the Tokelau Islands, where the sole mosquito is a dangerous species responsible for the transmission of non-periodic filariasis. This insect, the container-breeding *Aedes (Stegomyia) polynesiensis* Marks, appears as yet unaffected by parasites in the Tokelau Group; and it is considered that a complete lack of immunity could well result in its proving unusually susceptible to infection with Malayan strains of *Coelomomyces stegomyiae* Keilin. Tree-hole-breeding *Toxorhynchites* mosquitoes having predaceous larvae, and mermithid nematodes which parasitize *Stegomyia* elsewhere, could conveniently be introduced into the Tokelaus at the same time. This Group consists of three widely separated atolls, one of which could be left untouched as a control, *C. stegomyiae* being introduced into another and *Toxorhynchites* and/or a mermithid into the third.

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## INTRODUCTION

ANOPHILINE mosquitoes are absent from that part of the Pacific east of 170°E, and from all of Micronesia with the exception of Guam. Neither are they found in any of the islands east of Australia and south of 20°12'S. There being a complete lack of insect vectors autochthonous malaria is thus unknown in New Caledonia, the Loyalties, Norfolk, Lord Howe, Fiji, the numberless small islands of the central and eastern Pacific and, over towards South America, Easter Island, the Galapagos and Juan Fernandez.

A few tiny and generally very isolated islands north of 20°12'S, west of 170°E and south of Micronesia are also free from this group of mosquitoes. The localities concerned are the Belep Group (a little to the north-west of New Caledonia), Nauru, Ocean Island and some small units of the otherwise *Anopheles*-ridden and malarious New Hebrides and Solomons.

Biologists have long known that a major part of the Pacific is malaria-free, although lying within latitudes elsewhere synonymous with a high incidence of the disease. There have been differences of opinion as to whether or not anophelines are able—and ever likely—to become established in this zone.

A quarter of a century ago, attention was being directed to the possibility that ships sailing from Melanesian or other malarious localities might be the means of an introduction of *Anopheles* into the malaria-free zone of the Pacific (Buxton and Hopkins, 1927; Lambert, 1928; Hiermant and Cilento, 1929). In 1929 point was given to these warnings by the discovery of quiescent living anophelines between decks and in an insulated hold of vessels arriving at Auckland, New Zealand, from Indonesia and Malaya (Graham, 1939).

The great developments which have taken place in trans-Pacific air transportation in recent years have materially increased the chances of the accidental dispersal of dangerous insects (Laud, 1951). The potentialities of Pacific air travel in this connection had been recognized at an early stage, the airport insect control organization maintained at Honolulu, Hawaii, dating back to March 6, 1936 (Pemberton, 1941). Allied military authorities were fully aware of the health hazards arising out of the enormous development of surface and air traffic in the South Pacific during World War II, and special efforts were directed towards minimizing the chances of accidental introductions taking place. There was an inevitable period of confusion in the earlier and more desperate days of the Pacific campaigns, but late in 1943 the United States military forces in the Solomons and New Hebrides began taking thorough insecticidal measures aboard all eastbound aircraft (Lambert, 1949). After the end of hostilities Perry (1947) was able to report that "no anophelines were introduced as late as 1945 to the known non-malarious islands during the military occupation."

More recently, though, *Anopheles (Myzomyia) subpictus indefinitus* (Ludlow) (of the Philippine Islands, Formosa and Indo-China—Puri, 1949) has become established in Guam, the largest island of the previously anopheline-free Marianas (Yamaguti and LaCasse, 1950; Reeves and Rudnick, 1951). By February–March, 1948, when this mosquito was first reported from Guam, its larvae were already abundant in a wide variety of surface water habitats (Yamaguti and LaCasse). *An. subpictus indefinitus* is fortunately of no importance as a vector of *Plasmodium* (Simmons and Aitken, 1942), and by 1951 autochthonous malaria had still not been recorded from Guam (Hull, 1952). The findings of Reeves and Rudnick suggested that the Guamese strain of this anopheline is zoophilic, although Hull succeeded in inducing two reared females to feed on his arm under laboratory conditions. Both air and sea links are maintained between Guam and the Philippines—whence it seems most likely that the parent stock was introduced—but the actual means of introduction must now remain unknown. The date is to be

placed somewhere in the period February-March, 1945, to February-March, 1948, for all previous surveys up to and including one undertaken from the end of January to the end of February, 1945, failed to reveal the presence of anophelines (Bailey and Bohart, 1952).

At least one other mosquito has been introduced into a Pacific island where it was previously unknown since the end of World War II, Laird (1954a), having collected abundant larvae of *Culex (Culex) bitaeniorhynchus* Giles near Noumea, New Caledonia, in November, 1952. Several previous surveys, including the intensive ones of the war years, had not disclosed the presence of this species on the island. Once again the actual means of introduction is unknown, but there are regular sea and air links between Noumea and Sydney, Australia, where *C. bitaeniorhynchus* occurs.

Passing over for the present the numerous documented mosquito introductions of earlier years, the fact that two such introductions have taken place in the Pacific so recently is evidence enough that existing quarantine procedures are inadequate. A still more alarming illustration of this is the fact that 28 insect species, nine of them injurious to agriculture, became established in Hawaii aided by the agency of aircraft between 1944 and 1947 (Van Zwaluwenburg, 1947)—and this despite the efficiency of the airport insect control organization at Honolulu, which, besides being the longest established, is at least the equal of any other in the Pacific.

It must, of course, be borne in mind that relatively few species of *Anopheles*, are to be reckoned efficient vectors of *Plasmodium*. "Anophelism without malaria" is a well known and widespread phenomenon in marginal Pacific territories. It is normally the rule south of 19°S in Australia (Ford, 1950), it has been noted in Australia's Northern Territory (Black, 1950) and it has applied thus far in Guam (Hull, 1952). *Anopheles (Myzomyia) annulipes* Walker actually occurs above 10°S in Tasmania (Lee and Woodhill, 1944), far to the south of the southern limit for autochthonous malaria mentioned by Ford.

For all that, there can be no denying the gravity of the public health problem which would attend the establishment of a really dangerous anopheline in a Pacific island having a non-immune population; and just such an anopheline is present along the south-western boundaries of the malaria-free zone. *Anopheles (Myzomyia) farauti* Laveran is the only anopheline occurring in the New Hebrides, where *Plasmodium vivax*, *P. falciparum* and *P. malariae* are all endemic (Buxton and Hopkins, 1927; Laird, 1954), and is the only constantly dangerous vector on the Australian mainland (Ford, 1950). This species and the closely related *A. (Myzomyia) punctulatus* (Dönnit) are by far the most important, if not the only vectors in New Guinea, the Bismarck Archipelago and the Solomon Islands.

Buxton and Hopkins (1927) pointed out that in the New Hebrides (*An. punctulatus*) = *An. farauti* "is not a specialist in its breeding places, and it would easily establish itself in Fiji or Samoa, especially as there are taro swamps close to the quay at Suva, Fiji, and almost in the main street of Apia, and Pago Pago, Samoa." This viewpoint was adopted by many later investigators, one of whom claimed that as *An. punctulatus* and (its variety *molluccensis*) = *An. farauti* "have the most adaptable larvae of all known *Anopheles* . . . they may be expected to extend their range beyond the New Hebrides and become established in new localities." (Mumford, 1912.) Taylor (1943), on the other hand, contended that there has been ample opportunity in the past for eastward introductions of anophelines beyond the 170°E meridian to have been effected, "by means of inter-island lugger and small steamship travel." While admitting the possibility that aircraft might effect such introductions, he wrote that "supposing some Anophelines did elude the vigilance of the Air Force hygiene staff . . . I do not think that Anophelines or other mosquitoes would obtain a foothold in 'American Polynesia' since the fish *Gambusia affinis* has long been established on many of the islands in the

Central Pacific. . . . Therefore I do not think that any introduction of *Anopheles* could survive."

Taylor, while overrating the abilities of top minnows insofar as Pacific mosquito larval habitats are concerned, raised a point which often crops up in discussions on anopheline distribution in this region. Namely, that over a long period of time, there has been ample opportunity for an eastward dispersal of anophelines to be effected by human agency. The case of the New Caledonian area is particularly relevant. There was frequent traffic between this area and nearby malarious islands long before the existence of quarantine regulations (Perry, 1950), the narrowest gap—that separating Maré (Loyalties) from Aucityun (New Hebrides)—being only 210 kilometres wide. Again, residents of Fiji often recall the many flights by military aircraft between the New Hebrides, the Solomons and Viti Levu in the early days of the war in the Pacific, before adequate arrangements had been made for aircraft disinsection.

There are three possible explanations for this state of affairs. The first is that we are dealing with a genus which has already reached its maximum limits of distribution; the second, that the combination of circumstances necessary for the successful penetration of the malaria-free zone by *Anopheles* from western Melanesia has simply not yet arisen; and the third, that some ecological barrier is operating to prevent the establishment of anophelines within this zone.

As to the first of these suggestions, there is certainly some support to be derived for it from the decreasing representation of the tribe Anophelini in the island groups to the southeast of New Guinea. Twenty-two adequately characterized anophelines of the genera *Bironella* (subgenera *Bironella* and *Brugella*) and *Anopheles* (subgenera *Anopheles* and *Myzomyia*) are known from Australasia, together with a number of established and probable subspecies (King, 1949: Table 23). Sixteen of these, representing all four subgenera, occur in New Guinea. Eight of the latter group, together with two indigenous species, are found in Australia where, however, the subgenus *Brugella* is unknown. The range of *Anopheles* (*Anophles*) does not extend east of New Guinea, only two subgenera occurring in New Britain and the same number in New Ireland and in the Solomons. Lee and Woodhill (1944) recorded *An. (Myzomyia) subpictus* Grassi from New Britain, but subsequent authors have not accepted this. At least three anophelines do occur in New Britain, *B. (Bironella) gracilis* Theobald, *An. (Myzomyia) punctulatus* (Dönnitz) and *An. (Myzomyia) farauti* Laveran (Laird, 1946). The last-named species (and possibly *An. punctulatus*) is found in New Ireland (Lee and Woodhill, 1944), as is *B. (Brugella) hollandi* Taylor (Taylor, 1934). Both these *Anopheles* and *B. hollandi* as well are also established in the Solomons (Belkin et al., 1945).

As a result of intensive studies undertaken by American entomologists on Guadalcanal during World War II, four additional species of the subgenus *Myzomyia* were described. One of these, *An. kolensis* Owen, may in reality be a hybrid between *An. punctulatus* and *An. farauti* (Woodhill, 1945; Røzeboom and Knight, 1946). The others, *An. lungae* Belkin and Schlosser, *An. solomonis* Belkin et al., and *An. nataliae* Belkin form a closely interrelated complex. *An. lungae* is the only member of the complex to have been collected outside the Solomons, Hoogstraal having obtained specimens referable to this species in northern New Guinea (King, 1949).

Whether or not as many as seven species of anophelines are to be recognized from the Solomons, it is quite certain that only one, *An. farauti*, is present in the New Hebrides (Perry, 1915; Daggy, 1945; Røzeboom and Knight, 1946; Reid, 1947). This, the most ubiquitous anopheline of the Australasian Region, utilizes an extremely wide range of larval habitats. It occurs from the eastern islands of Indonesia (being one of the seven Australasian anophelines to have penetrated into the Oriental Region—Bonme-Wepster and Swellengrebel, 1953) through New Guinea to the Northern Territory and Queensland in Australia, as well as in the

Melanesian island groups already mentioned. Roberts (1918) was of the opinion that Ingham ( $18^{\circ}38'S$ ) is the most southerly place in Australia reached by *An. farauti*, but more recently adults have been recorded as far south as Townsville ( $19^{\circ}14'S$ ) (Mackerras, p.c., 1954); there are also unconfirmed records from Mt. Isa and Hughenden, inland from and to the south of Townsville (Taylor, 1943) and from Chinchilla inland from Brisbane (Lee and Woodhill, 1944), but it would appear that these are almost certainly erroneous. As far as is at present known the most southerly point attained by this species anywhere in its range is Aneityum, New Hebrides ( $20^{\circ}12'S$ ) (Laird, 1954).

Anophelines, which have obviously pushed out into the South Pacific from the direction of the New Guinea area, thus extend no further than the southern New Hebrides, the representation of subgenera and species diminishing progressively (apart from the instance of "explosive speciation" in the Solomons) as the distance from New Guinea increases. Our knowledge of the Pacific mosquitoes covers too short a period of time to be of much assistance in assessing the stability of this distributional picture. We do know from early mission writings that *Anopheles* must have reached Aneityum before 1850 (Inglis, 1887), and there are repeated references to the absence of "ague" from the Loyalty Islands and Future (New Hebrides) which are still just outside the perimeter of the malarious zone. On the other hand, there is good evidence that malaria is still spreading inland in Papua, and has only become established in two of the Polynesian outliers of the Solomons, Sikaiana and Rennell, during the last three decades (Lambert, 1949). This of course need not imply recent anopheline introductions, but might be due to the infection of already-present *Anopheles* by gametocyte-carrying travellers. In this connection, although Lambert (1931) found neither anophelines nor evidence of malaria at Rennell, Hogbin (1930) stated that ". . . there is still no malaria on Rennell Island, an uplifted coral atoll to the south of the Solomons which is infrequently visited by white men. Here the *Anopheles* have been found, but they are as yet uninfected."

To make up for the unsatisfactory state of our knowledge of anopheline dispersal in the South Pacific, we have a considerable body of evidence relating to culicine introductions. Thus Gill (1883) wrote of the old men of Penrhyn, Manihiki and Rakahanga (Northern Cook Islands) as having assured him that no mosquitoes were present on these atolls until some years after the introduction of Christianity; "although mosquitoes were (accidentally) conveyed to Penrhyns and Rakaonga in 1859, and to Manihiki as lately as 1862, in water-casks filled at Rarotonga, and they are now plentiful on all three islands." Rougier (1926) stated that Christmas Island (Line Islands) received its first mosquitoes in 1917, through the medium of a barrel of drinking water brought from Tahiti. The dispersal of *Culex annulirostris* Skuse in recent years has been commented on by Laird (1954a, 1954b, 1955a). Members of the *scutellaris* group of *Aedes* (*Stegomyia*) were probably carried about between the Polynesian island groups in the drinking-water containers of pre-European ocean-going canoes (Davis, 1949), *A. (Stegomyia) tongae* Edwards having reached Sikaiana, Solomons, from Tonga in similar manner (Buxton and Hopkins, 1927).

The fact that mosquitoes of the genera *Culex* and *Aedes* have greatly extended their area of distribution in the Pacific in comparatively recent years while anophelines have not done so, can be explained very simply on the grounds of the life histories of the mosquitoes concerned and the means of dispersal available to them.

Oceanic distances in the Pacific are so great as to virtually rule out the dispersal of mosquitoes from island group to island group by natural agencies. On the other hand such agencies, particularly wind, must undeniably have played a part in the dispersal of mosquitoes among closely adjacent islands. Thus Makuluva, located on the fringing reef off Lauthala Bay near Suva, Fiji, is practically without mosquito larval habitats of any kind and normally has no mosquito nuisance; but from time

to time strong offshore breezes carry large numbers of *Aedes (Stegomyia) pseudoscutellaris* (Theobald) to the islet from the mangrove swamps of the Rewa Delta which are three to five kilometres distant. These never succeed in establishing themselves in significant numbers at Makuluva because of the lack of suitable breeding places. Inglis (1890), referred to a possible airborne introduction of mosquitoes into Tonga in the early days of the Wesleyan Mission, which was established in Tongatapu in 1928-29. He wrote: "One of the Wesleyan missionaries told me that when they went to Tonga, there were no mosquitoes there; but on one occasion when the missionaries were assembled at their annual conference, one of them looked out at a window, and there was a cloud of mosquitoes in front of the house. Whence they came no one could tell. They had been wafted no doubt by the wind from some other island or group. But they maintained their footing there ever after." The only Tongan mosquito at all likely to indulge in such a mass flight is the widespread *Aedes (Aëdimorphus) vexans*, var. *nocturnus* (Theobald). This species periodically appears in large numbers in Fiji (Paine, 1913). Whether or not it or some other mosquito was responsible for the swarm recorded from Tonga, the explanation possibly lies in exceptionally favourable breeding conditions suddenly bringing about a great increase in population of a species previously present but not in sufficient numbers to bring itself under notice as a pest. On the other hand, *A. vexans* flights have been known to reach high altitudes in North America, and then to be displaced by winds for distances of up to 370—perhaps 740 kilometres (Horsfall, 1934). Buxton (1935) was of the opinion that this insect "owes its wide and erratic distribution to winds" rather than to human agency.

*A. vexans nocturnus* is the only widespread Pacific mosquito in regard to the distribution of which winds may have played an important part. Human agency has favoured certain other species, notably those which utilize "domestic" water containers as larval habitats. The probable inter-island transportation of *Aedes tongae* and various other members of the *scutellaris* group by means of canoes has already been commented on. The cosmopolitan *Aedes (Stegomyia) aegypti* L. and *Culex (Culex) pipiens fatigans* Wied. are well known to have been broadcast throughout the warmer regions of the world aboard ships, through their facility of maintaining themselves by breeding in water containers of various kinds. This has happened in the South Pacific as elsewhere. Thus *Culex p. fatigans* is known to have been introduced into Hawaii on board a sailing ship from Mexico in 1826 (Bryan, 1934), while *A. aegypti*, which is known to have abounded on French naval vessels in the Pacific at the turn of the century (Perry, 1950), is still most commonly found in the immediate vicinity of the major ports— Noumea, Suva, Apia and Papeete. The only distinctively Pacific species of *Culex* which has succeeded in rivalling these cosmopolitan insects in the matter of dispersal is *C. (Culex) annulirostris* Skuse; and significantly, *C. annulirostris* has a very wide range of larval habitats and is almost alone among the members of its genus native to the region in having developed strongly "domestic" leanings.

The Pacific anophelines are all surface water breeders, and the occurrence of larvae of any of them in any kind of artificial container is a rare event (Perry, 1915a). This fact alone very greatly reduces the chances of successful introductions of *Anopheles* being made into the malaria-free zone of the Pacific by means of shipping, for only those anophelines which board a ship at a malarious port in this area could leave it again at the end of a voyage—there being no possibility of their finding suitable larval habitats aboard, they would be denied the opportunity (always afforded to "domestic" mosquitoes) of increasing or even maintaining their population. The shipboard survival of the imagines themselves is rendered less likely in direct proportion to the duration of the voyage, males dying in consequence of being denied their natural foods and females running the risk of being killed at each blood meal (Laird, 1951a).

Inter-island shipping thus greatly favours the dispersal of certain "domestic" non-anopheline mosquitoes over that of anophelines in the South Pacific. The ability to maintain and increase their population level on board ships has permitted domestic species to spread far and wide within the island groups of this region, and if full consideration is accorded the difficulties besetting insects lacking this ability it ceases to be a matter for undue surprise that *Anopheles farauti* and its relatives have not thus far had their ranges extended into the malaria-free zone in consequence of sea transportation.

This picture has been radically altered in recent years by the development of air transportation in the Pacific. The relatively brief flying time between islands separated by many days or weeks in terms of previously available types of transport, does away with any need for mosquito populations to be self-sustaining whilst in transit. Furthermore, island airfields are more likely to be surrounded by actual and potential anopheline larval habitats than are docks, and this favours accidental introductions taking place (Laird, 1951a). It is now well known that mosquitoes are able to survive the conditions of temperature, pressure and vibration encountered in even the longest of flights in aircraft. Indeed the only factor operating against the chances of survival of mosquitoes in these as compared with ships is the greater prospect of success attendant upon insecticidal treatment of aircraft in view of their comparatively small size and the fewer available sheltering places for insects within them.

At the same time, a certain sequence of events must be followed through before even aircraft can bring about the establishment of mosquitoes in new territories. First of all, a sufficient number of males and females, or of fertilized females, must board the aircraft at a departure point. In the case of the anophelines, which are nocturnally active, this presupposes night activity aboard the aircraft concerned. An aircraft being loaded or unloaded at a tropical airfield is usually standing upon a sealed tarmac or at least upon well drained and open ground, and this introduces the factors of distance from the nearest larval habitats and adult sheltering places. Having boarded a departing aircraft there is the hazard of insecticidal spraying *en route* or upon arrival at the destination to be contended with; the time of day must then be suitable for the escape flight of surviving anophelines. These must now be able to locate places suitable for oviposition within their own flight range of the aircraft. They must avoid the attacks of predators until oviposition has taken place, and their progeny must not only survive the vicissitudes of hatching but must also run the gauntlet of biological enemies and obtain suitable food as well. The comparative handful of adults emerging in due course must now face all these hazards of the post-aircraft phase themselves. Small wonder indeed that the number of known instances of successful mosquito introductions being made in this manner is so small.

Even so, at least one such airborne introduction—that of the Australian *Aedomyia catasticta* Knab into Nandi Airport area, Fiji (unpublished report, Fiji Medical Department, August, 1948)—has taken place in the South Pacific. Other recent appearances of locally unknown mosquitoes in the vicinity of South Pacific ports—for example, those of *Aedes (Ochlerotatus) vigilax* (Skuse) at Suva in 1910 (Paine, 1943), on Espiritu Santo in 1911 (Perry, 1946) and on Guadalcanal in 1953 (p. 8); and of *Culex bitaeniorhynchus* near Noumea in 1952 (Laird, 1954a)—might be due to either ships or aircraft. When these facts are considered in the light of the numerous living and dead mosquitoes which continue to be intercepted on board aircraft by New Zealand quarantine officers (Laird, 1951, 1952a), of the discovery of a living female of *Anopheles (A.) pseudopunctipennis* Theobald aboard an aircraft arriving at Honolulu from California (Pemberton, 1944) and of the establishment of *An. subpictus indefinitus* in Guam, we are forced to recognize the likelihood of an ultimate introduction of anophelines into the malaria-free zone of the South Pacific through the agency of man. The fact

that this has not happened before now is hardly admissible as evidence that the conditions in this zone are unsuitable for *Anopheles*, and it can be explained perfectly adequately on the thesis that the full sequence of events which must prelude a successful anopheline introduction has simply not yet taken place. Its chances of taking place, however small they may be, cannot but increase with the passing of the years and the consequent development of faster and more frequent inter-island transportation.

There are, then, no grounds for assuming that the anophelines have already attained their maximum limits of distribution in the Pacific, and it is quite feasible that the combination of circumstances necessary for the successful penetration of the malaria-free zone by *Anopheles* has not thus far arisen. The question of whether some ecological barrier is operating to prevent the establishment of anophelines within this zone, cannot be dealt with so easily on available evidence. The literature on the ecology of Pacific mosquitoes is scanty, and is composed for the most part of scattered observations embodied in systematic papers or in general accounts of the Culicidae of specific island groups. So little is recorded about the parasites and predators of mosquitoes in this region and the larval feeding habits, that it is quite impossible to draw worthwhile comparisons between the larval habitats of the Pacific anophelines and superficially similar habitats in the malaria—and anopheline-free zone. During the war years a sample of Fijian surface water was freighted to the New Hebrides, where American military entomologists had no difficulty in raising *Anopheles farauti* to maturity in it, but this is surely little more than a demonstration of the fact that mosquitoes require water for their larval development, in view of the wide range of waters from which *An. farauti* has been recorded in the malarious islands. Such a demonstration lacks point in the absence of the multitude of ecological factors the impact of which can be gauged only under actual field conditions.

An answer as to whether an ecological barrier is operating to keep *Anopheles* out of the anopheline-free island groups could most speedily and convincingly be obtained by deliberately introducing *An. farauti* into a selected island of this zone under controlled conditions. Provided that the island concerned were small enough, and far enough away from populous islands, such an introduction, if successful, could probably be brought under complete control at the end of the demonstration. As to whether or not a biologist is morally justified in urging a demonstration of this kind upon the relevant authorities is another question altogether. Such an experiment would increase the chances of the very event that it is desired to avoid taking place, through the possibility of accident in transit between the *An. farauti* source and the place selected for the field studies, and because of the hazard that subsequent control measures might not prove effective. In any case, even a successfully concluded demonstration would provide data applicable to one island only, and any island small enough and isolated enough to be safely employed in this connection would not be biologically comparable with the larger and populous high islands of the anopheline-free zone.

However, if elaborate and costly anti-mosquito measures are to be envisaged for the future to guard against accidental introductions of *Anopheles* into this zone—these measures including the elimination of all suitable larval habitats within a radius of at least half a mile of airports and docks handling traffic from places where such mosquitoes occur—the authorities concerned are certainly warranted in asking for evidence that anophelines could in fact establish themselves once introduced. The necessary evidence is not to be had from existing literature, and for the reasons stated above would not be forthcoming from the results of a deliberate introduction into a small island under controlled conditions.

Following an assignment by the New Zealand Air Board to undertake a two-year study of mosquito ecology in the South Pacific, with particular attention to problems of anopheline distribution, it was thus decided to proceed by making

as detailed comparisons as possible between mosquito breeding conditions in malarious parts of the western Pacific and various anopheline-free islands. The ecology of mosquito larvae, unlike that of the imagines, lends itself to rewarding study during relatively brief periods of field work. In view of the amount of time available for the covering of a very wide area, the investigation was consequently restricted to larval habitats. It was felt that the best promise of significant results lay in a study of larval habitats in general rather than in a survey of the biology of selected mosquitoes. The sketching of an overall picture of larval ecology in as many parts of the tropical South Pacific as possible would help to place this rather neglected field of mosquito research on a systematic basis and indicate trends which might not only help to explain anopheline distribution but also throw fresh light on other problems of mosquito biology within the region under consideration.

#### ACKNOWLEDGMENTS

This investigation was initiated by the Royal New Zealand Air Force and was carried out under the direction of the D.M.S.(Air), Group Captain A. H. Marsh, M.B., Ch.B., D.T.M. & H., Q.J.L.P., R.N.Z.A.F. Among those who were instrumental in obtaining for it the necessary official support were Sir Charles E. Hercus, K.B.E., Dean of the Medical School, University of Otago, and Air Commodore P. B. Lee Potter, O.B.E., M.D., R.A.F. Technical assistance was provided by the N.Z. Department of Scientific and Industrial Research, which also made an annual grant to cover all field expenses. Inter-island transport was by flying boats of No. 5 Squadron, R.N.Z.A.F. The base laboratory was located at the Colonial War Memorial Hospital, Suva, and was made available by the Government of Fiji; other facilities within that Colony were afforded by R.N.Z.A.F. Station, Lauthala Bay.

Approval for field work in their territories was freely granted by the French and British authorities in the South Pacific, and the Western Pacific Fish Commission supplied one of its vessels for a visit to the isolated islands of Rennell and Bellona. Assistance within Australia, including the provision of a vehicle for field work in Queensland, was supplied by the Royal Australian Air Force. The South Pacific Commission extended laboratory and other facilities in New Caledonia. Among the many private individuals who offered their willing help in the field, Mr. A. C. Stevenson of the Aneityum Logging Company not only arranged housing on two occasions but also offered his launch for the trip to Futuna which could not otherwise have been visited.

My wife assisted in both field and laboratory throughout the project. By her help, often under most trying conditions, she contributed very greatly towards its successful completion. Mr. T. M. Skerman of the Oceanographical Observatory, D.S. & I.R., very kindly made a number of collections, including the only ones available from Savai'i, Western Samoa, during a cruise on H.M.N.Z.S. "Lachlan." A year-round record of water temperatures from the most southerly anopheline larval habitat in the Pacific was kept by the meteorological staff at Aneityum through the good offices of Mr. W. Roberts of S.P.A.T.C., Vila, New Hebrides. At all times, invaluable liaison was maintained by Mr. G. W. Markham, Secretary-Executive Officer of the N.Z. Defence Research Organization.

Prompt and unfailing assistance in the frequently most difficult matter of the identification of aquatic insects from little-known islands was always provided by the Commonwealth Institute of Entomology, London. My thanks are also due to the following for determining collections of aquatic animals and plants, often at the expense of their own current researches.—Prof. G. W. Prescott, Michigan State College (Chlorophyta and Cyanophyta); Dr. Fay Daily (Charophyta); Messrs. L. A. S. Johnson, National Herbarium of N.S.W., P. Sarlin, Dept. of Agriculture, New Caledonia, J. Patham, Dept. of Agriculture, Fiji, V. D. Zotov, N.Z.D.S. & I.R., and Miss Ruth Mason, N.Z.D.S. & I.R. (Phanerogams); Prof. H. W. Mander, University of Nebraska (Turbellaria); Mr. G. R. Russell (Rotatoria); Dr. K. G. Wingstrand, Lund University; Dr. V. Brehn, Lund (Cladocera); Drs. K. Lindberg, Lund, and P. A. Chappuis, Toulouse (Copepoda); Dr. J. P. Harding, British Museum (Ostracoda); Drs. L. B. Holthuis, Leyden, C. H. Edmondson, B. P. Bishop Museum and D. E. Hurley (Malacostraca); Dr. J. T. Salmon, Victoria University College (Collembola); Dr. M. A. Liefrinck, formerly Director of the Zoological Museum, Bogor, Indonesia (Odonata); Mr. D. E. Kimmins, British Museum (Plecoptera); Prof. H. B. Hungerford, University of Kansas, and Mr. E. S. Brown, Commonwealth Institute of Entomology (Homoptera); Dr. G. H. Satchell, University of Otago (Psychodidae); Drs. Elizabeth N. Marks, University of Queensland, and J. N. Belkin, University of California (both of whom helped

in the determination of Culicidae belonging to groups upon which they are currently working); Dr. W. W. Wirth, U.S. National Museum (Tendipedidae and Helcidae); Dr. J. Balfour-Brown, British Museum (Coleoptera); Dr. Karl Viets, Bremen (Hydracarina); Dr. R. R. Forster, Canterbury Museum (Araucida); Mr. R. K. Dell, Dominion Museum, Wellington (Mollusca); Henry W. Fowler, Academy of Natural Sciences of Philadelphia (Fishes); and Dr. Karl P. Schmidt, Chicago Natural History Museum, Walter Brown, Stanford University and Robert F. Inger, Chicago Natural History Museum (Amphibia).

Much of the paper was written at the University of Malaya, the library resources of which proved invaluable.

## Studies of Mosquitoes and Freshwater Ecology in the South Pacific.

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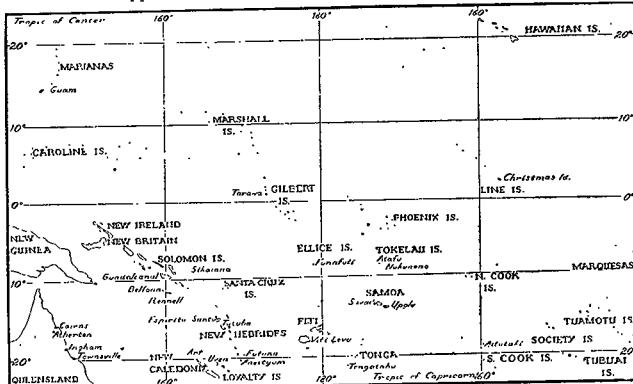
This contribution embodies the results of studies undertaken while the author was serving as (Sqn. Ldr., Medical Branch) in the Royal New Zealand Air Force. The project was initiated by that Service, and was supported by a grant from the N.Z. Department of Scientific and Industrial Research. Publication authorized by the Chief of Air Staff, R.N.Z.A.F.

## MATERIAL AND METHODS

THE initial plan for this investigation included provision for visits to the New Hebrides (Espiritu Santo, Aneityum and the anopheline-free islands of Tутуба and Futuna), to New Caledonia and the nearby Belep Islands, to the Loyalties and to the Polynesian outliers of the Solomons. It was proposed to use Fiji as a base and—together with New Caledonia—as a source of material for comparison with that collected in the malarious zone.

These objectives were all attained in due course, and additional field trips, notably to Guadalcanal and Queensland, were incorporated into the programme. At the same time, it was possible on occasion to widen the scope of the study by taking advantage of routine Service flights to various places east of Fiji. Unscheduled and often very brief visits were made in this manner to Tonga, Upolu, Aitutaki, Tarawa, Funafuti and the Tokelau Islands. A number of additional collections were made, notably on Savai'i, Western Samoa, by Mr. T. M. Skerman. The various localities concerned are indicated in the accompanying sketch map (Text-fig. 1).

It was decided to make as close a study as possible of the larval ecology of South Pacific mosquitoes, with a view to assessing the suitability of habitats in the malaria-free zone for anophelines. At the same time, it was felt that not only surface water but all types of potential larval habitats should be investigated, whether these appeared suitable for anophelines or not, in order to obtain an



TEXT-FIG. 1.—Sketch map showing the places visited together with some other islands mentioned in the text.

overall picture of the utilization of mosquito breeding places in general throughout the area of the survey. Thus no attempt was made on any field trip (other than that to Queensland, where container habitats were neglected in order that as many ground pools as possible could be examined during a fortnight's work) to select any particular types of water body over others, regardless of their nature or whether or not they held mosquito larvae.

The great majority of the water bodies studied were of small size, for the tropical Pacific is notably lacking in the lakes, large ponds and extensive swamps (other than mangrove swamps<sup>5</sup>) and marshes which characterize many other areas. Each water body visited was studied for about one hour. First of all its nature and measurements were noted and it was photographed, frequently in kodachrome, as an aid to future comparisons. Water and air temperatures were taken, and any foulness of the water due to pollution by animals or vegetable decomposition was recorded. The hydrogen ion content of the water was estimated by means of a Lovibond Comparator, employing B.D.H. indicators and caliometric discs graduated by 0·2 from pH 5·2-6·8 (bromo-cresol purple) and from pH 6·8-8·4 (phenol red). In those cases where the pH value fell outside this range, or where the quantity of water available was extremely limited, a B.D.H. universal indicator (pH 1·0-11·0) was used. Brackishness was roughly checked by means of a hydrometer, but the lack of both time and facilities prevented the accurate estimation of chlorides.

A 10cc water sample was collected, and on return to the field base this was centrifuged and the concentrate searched for protozoans and unicellular algae by means of a field microscope. This was merely intended as a check on the availability of micro-organisms as larval food, and precise determinations were seldom made. It was sometimes possible to take into the field a Zeiss-Winkel GF 525 microscope with phase contrast equipment and an integral illuminant powered by a 6v car battery, and this greatly facilitated the identification of living Protozoa.

A white-enamelled ladle of just under 210cc capacity was employed in dipping for mosquito larvae in surface water and the larger containers, while coconut husks and other such containers, and leaf axils, were repeatedly flushed out with water to dislodge mosquito larvae and any other insects present. Samples of any macroscopic aquatic vegetation were gathered by hand for pressing. A Ward's aquatic apron net having a hinged mesh cover to guard against undue choking with vegetation was used in the bottom-sampling of the larger water bodies. The consequent muddying of the water sometimes served to advantage in forcing to the surface the more cryptic mosquito and midge larvae. Any fish present were secured by poisoning them with rotenone (five per cent.).

The collection of such surface-film arthropods as Gyrinidae, the water-skating Hemiptera and *Dolomedes* spiders posed something of a problem initially, the rapid and unpredictable movements of these creatures making it a difficult matter to net them. It was then found that the shaking of a few drops of chloroform onto the surface film both stilled the arthropods actually contacted by the reagent and caused the film itself to break up so that the surface-dwelling animals dropped helplessly through it. Once submerged, these were easily secured with the larva dipper. Comprehensive collections could be obtained in this manner in a very much shorter time than with a net, and even the gathering of fast-moving *Rhagovelia* (Hemiptera) from torrents became a simple matter.

Wherever practicable, samples of mosquito larvae were taken back alive to the field laboratory for parasitological examination and gut dissection. For space-economy—as predators frequently attack one another when confined together in tubes, of which only a limited number can be conveniently carried during a day in the field—the other organisms were usually killed and preserved in 70 per cent. alcohol immediately upon collection.

Only two preservatives were employed, both for consideration of weight and to simplify field procedures. Formalin was used for algae and micro-organisms

generally, and for the smaller phanerogams. A few drops of 40 per cent. formaldehyde were simply added to a concentrate of material in the natural medium in a small tube. It was found that by far the best results with rotifers, particularly bdelloids, were to be had by killing the specimens in boiling water first. Seventy per cent. alcohol was employed for all larger animals. Mosquito larvae were usually killed in nearly-boiling water before preservation. They were subsequently cleared in xylol and mounted in neutral "Sira" mountant (Stafford Allan and Sons). It is perhaps worth noting that the shortcomings of permanent preparations made in this manner—which are in many respects less satisfactory than preparations made by elaborate techniques unfortunately unsuited to field conditions—are largely compensated for if phase contrast methods are employed in their examination. In many cases even ectocommensal ciliates remaining attached to the larvae are sufficiently well preserved for specific identification, the macronucleus and other organelles, although unstained, showing clearly by phase contrast.

A record sheet was filled out for each collection. These sheets, stapled together in tens, were numbered quite adventitiously (A1-10, B1-10 . . . aA1-10, etc.) before departing from base prior to each field trip. They were subsequently filed in order of use, for as two collectors were working, frequently in different localities, at the same time, it would not have been possible to keep to an orderly sequence of field numbers. All the material gathered at each water body was preserved in small tubes bearing the same number as the relevant data sheet. At the end of the project, the data sheets were systematically re-numbered in two series; from 1 onwards in the case of mosquito larval habitats and from 1<sup>1</sup> onwards in that of water bodies lacking mosquitoes.

In all, a detailed study was made of 372 mosquito larval habitats and of 83 water bodies in which no mosquitoes were present. Summaries of data for all these collections are presented in Tables I and II. From a consideration of all the field findings a classification of small water bodies lending itself to the systematic study of mosquito ecology was worked out, the 12 broad habitat categories defined therein (p. 131 ff.) being employed in these Tables. The nature of the bottom is given as 1 (bare), 2 (leaves and other organic debris), 3 (mud) and 4 (stones). The factors of foulness and shade are listed simply as plus or minus quantities, and water (surface) and air temperatures are given in degrees Centigrade. A useful rough index herein termed the "temperature factor" may be obtained by expressing the difference between the water- and air temperature readings as a plus or minus quantity in relation to the latter.

Mosquito larval abundance is listed simply as 1 (rare; no larvae evident on inspection and no more than 10 collected in 50 random dips), 2 (common; less than five larvae per dip but few dips altogether without larvae) and 3 (abundant; five or more larvae per dip). The presence of ectocommensal ciliates is indicated by an asterisk (\*) in the case of *Vorticella*, by a dagger (†) in that of *Epitylis* and by (‡) in that of *Zoothamnium*. Finally, my faunal and floral indices are designed to serve as an arbitrary guide to the complexity of the macrofauna and macroflora of the various habitats. To a large extent these figures reflect the relative permanency of the latter. The indices, ranging from 1 to 4, are computed as follows.—1, no macroscopic animals (other than mosquito larvae) or plants; 2, representatives of from one to four species of macroscopic organisms present; 3, representatives of from five to nine such species present; and 4, representatives of 10 or more such species present. No allowance is made for mosquito larvae in the faunal index in order that this may be viewed in relation to the occurrence and abundance of such larvae.

The collection data in Tables I and II, allowing of precise correlations with the records of all the aquatic organisms tabulated in the following pages, are presented in detailed fashion rather than as statistical analyses in order that they may lend themselves to integration with the results of other studies of this nature.

TABLE I  
Summary of data from mosquito larval collections,<sup>1</sup>  
PHYSICAL AND CHEMICAL  
FACTORS

Collection Number	Date	Locality	Bottom	Bottomness	Shade	Water Temperature	Air Temperature	Relative Humidity	Species	Squirts	<i>Culex pipiens fatigans</i> *	Larval Index	Pupal Index	Mosquito Index	REMARKS		
															Sewage		
1	10/6/52	TANAHWA Polluted stream		5	+	22	24	VIRI LEVU, FIJI				3	1	1			
2	3/8/52	ANILGAUHAT Whaling try pot		6	2	+	-	ANETYUM, NEW HEBRIDES				3	2	1			
3	4/8/52	ANILGAUHAT Marsh		2	2	...	+	24	20	7.1	<i>C. pipiens fatigans</i> *	3	2	2			
4	4/8/52	ANILGAUHAT		7	1	-	+	<i>C. annulirostris</i>				1	2	2			
5	4/8/52	ANILGAUHAT Half coconut shell		7	2	+	+	28	23	6.4	<i>A. s. scutellaris</i>	3	1	1			
6	4/8/52	ANILGAUHAT shell		1	3	-	+	24	23	7.0	<i>An. farauti</i> * <sup>†</sup>	2	4	3	1/10 <i>Spirodelta pleuston</i>		
7	5/8/52	Taro Pond ANILGAUHAT Pierced coconut shell		7	2	+	+	22	24	5.8	<i>C. annulirostris*</i>	3	1	1			
											<i>T. melanostomus</i>	3	2	1			
											<i>A. s. scutellaris</i>	3	2	1			
8	12/8/52	GATEVILLE		7	2	-	+	AORE, NEW HEBRIDES				3	1	1			
9	12/8/52	GATEVILLE Marsh		2	3	+	+	6.6 <i>A. perniciosus</i>				2	2	2	Cattle, 1/10 <i>Spirodelta pleuston</i>		
10	12/8/52	GATE Flooded grassy flat		3	3	+	-		7.2			2	2	2			
11	12/8/52	GANE Wheel rut		3	3	+	-			8.4 <i>C. annulirostris</i> * <sup>†</sup>		1	2	2			
12	13/8/52	RARUA Marsh		2	3	-	+	<i>An. farauti</i>				1	1	1	Cattle, dogs		
13	13/8/52	RARUA Half coconut shell		7	1	-	-	<i>C. annulirostris</i>				3	1	1			
14	15/8/52	RARUA Wheel rut		3	3	-	-	<i>C. annulirostris</i>				3	2	2	1/10 floating algal mat		
								<i>An. farauti</i>				1	1	1			
								<i>C. annulirostris</i>				2	2	2			
								<i>An. farauti</i>				1	1	1			
								<i>C. annulirostris</i>				3	1	1			
								<i>An. farauti</i>				3	1	1			

15	15/8/52	SOUTHERN HILL.	1	2	+	+ 23 24 6.6	<i>C. fraudatrix*</i>	3	2	Pigs, 9/10 <i>Spirodelta</i> pleuston
16	16/8/52	SOUTHERN HILL	1	2	+	+ 23 25 7.0	<i>C. fraudatrix</i>	1	2	2 10/10 <i>Spirodelta</i> pleuston
17	19/8/52	PALIKELO Borow pit	1	3	—	+ 25 22 7.4	<i>An. farauti</i>	1	3	Cattle
18	19/8/52	PALIKULU Borow pit	1	3	—	— 25 22 7.4	<i>C. annulirostris*</i>	1	1	
19	19/8/52	LUCANVILLE 44 gallon drum	6	1	—	+ 25 22 6.8	<i>C. pipiens fatigans</i>	3	1	
20	19/8/52	LUCANVILLE Puddle	3	3	—	+ 25 22 7.2	<i>C. pipiens fatigans</i>	3	2	
21	19/8/52	LUCANVILLE Ponded ditch	4	3	—	+ 24 21 7.8	<i>An. farauti</i>	3	1	
						TUTUBA, NEW HEBRIDES				
22	22/8/52	SOUTHERN HILL Forest pond	1	2	+	+ 24 22 6.6	<i>C. fraudatrix*†</i>	1	2	Pigs, 10/10 <i>Spirodelta</i> pleuston
23	22/8/52	SOUTHERN HILL Hole in buttress root	7	2	—	+ 23 22 6.6	<i>C. pacificus</i>	1	1	
24	22/8/52	SOUTHERN HILL. Forest pond	1	2	—	+ 23 22 6.6	<i>C. fraudatrix</i>	1	2	2 10/10 <i>Spirodelta</i> pleuston
25	22/8/52	SOUTHERN HILL. Rat-gnawed cacao pods	7	1	—	+ 22 24 6.0	<i>T. melanopterus</i>	3	2	
26	23/8/52	SOUTHERN HILL. 44 gallon drum	6	1	—	+ 25 23 6.8	<i>C. femoratus</i>	3	1	
						<i>C. annulirostris*</i>				
27	23/8/52	SOUTHERN HILL. Forest pond	1	2	+	+ 23 22 7.0	<i>C. pacificus</i>	2		
28	23/8/52	SOUTHERN HILL. Forest pond	1	2	+	+ 23 22 6.8	<i>C. fraudatrix*†</i>	1	2	Pigs, 10/10 <i>Spirodelta</i> pleuston
29	24/8/52	Le France, coast Concrete trough	6	1	+	- 23 25 8.4	<i>C. femoratus*</i>	1	3	Pigs, 10/10 <i>Spirodelta</i> pleuston
						<i>C. annulirostris*</i>				
						<i>C. pipiens fatigans*</i>	1	3	Cattle, <i>Spirogyra</i> throughout	
						ESPiritu Santo, NEW HEBRIDES				
30	26/8/52	Loganville. Puddle	3	2	+	+ 25 23 7.4	<i>An. farauti*</i>	3	2	Pigs
31	28/8/52	RIVER RIVER Ponded ditch	4	3	+	+ 27 23 7.4	<i>C. annulirostris*†</i>	3	3	Cattle, pigs, submerged algal masses throughout
						<i>C. basivittatus*</i>				
						<i>C. annulirostris*†</i>	2			
						<i>An. farauti</i>	1			

<sup>†</sup> All generic names are abbreviated herein, the full names together with their authorities being listed in the following section.

TABLE I.—Continued.  
PHYSICAL AND CHEMICAL FACTORS

Collection Number	Date	Locality and Habitat	Habitat Category of Bottom	Bottom Prolificness	Shade	Temperature	Relative Humidity	Moisture Index	Abundance Index	Species Index	REMARKS			
											C. sitens	G. stellatus	G. annulirostris	
32	1/9/52	Venue Islet Pool in coral just above high water mark	11	1	—	28	23	8.4	3	1	1	1	1	
33	2/9/52	Bias, Tasmaloun	2	3	+	...	...	6.8	An. farauti*	3	2	2	Cattle	
34	2/9/52	Marsh, Nevara R., 150m	4	3	—	+	...	7.2	An. farauti	3	1	2		
35	3/9/52	Ponded stream, Nevara R., 250m	6	1	—	+	21	20	C. femininus	3	2	1		
36	3/9/52	Large rock crevice, Nevara R., 325m	6	2	+	+	...	6.2	An. farauti*	1	2	1	Decomposing leaves on surface	
37	3/9/52	Large rock crevice, Nevara R., 600m	8	1	+	+	...	6.8	T. foliacea	2	2	1		
		Leaf rock, Afocain tumata							VITI LEVU, FIJI					
38	21/9/52	Syrigatora Marsh	2	3	+	+	23	21	G. annulirostris*	1	3	2	Cattle	
39	22/9/52	Jautora Ponded ditch	4	3	+	+	...	7.4	G. annulirostris*	3	2	2	Cattle	
40	28/9/52	Lorihau stream Flowing stream	5	4	—	+	29	30	6.8	C. albincris	3	2	2	Submerged algal masses
									NEW CALEDONIA					
41	18/11/52	Tontouta Ponded ditch	4	3	—	+	34	35	A. vexans nocturnus	3	2	2		
42	18/11/52	Tontouta Ponded ditch	4	3	—	+	34	35	G. annulirostris	2	2	2		
43	18/11/52	Tontouta Ponded ditch	4	3	—	+	29	33	G. annulirostris	1	2	2		
44	20/11/52	Aust. Vara Salt marsh	10	3	+	+	30	24	A. vigilax	3	2	2	Stranded algal sheet	
45	21/11/52	Aust. Vara Ponded ditch	4	3	—	+	30	29	C. stictus	3	2	2	Submerged algal masses	
46	21/11/52	Aust. Vara Ponded ditch	4	3	+	—	31	29	C. bilacanthorhynchus	2	3	2		
									C. annulirostris*	3	2	2	Cattle, submerged algal masses	
									G. bilacanthorhynchus					



TABLE I.—*Continued.*  
PHYSICAL AND CHEMICAL  
FACTORS  
BIOLOGY  
REMARKS

82	20/2/53	Mission Bay Transient forest pool	3	2	-	+	....	6.8	<i>A. vexans nocturnus</i>	2	1
									<i>A. s. scutellaris</i>		
83	20/2/53	Mission Bay Tree hole	7	2	+	+	....	7.4	<i>A. s. scutellaris</i>	2	2
84	20/2/53	Mission Bay Tree hole	7	2	+	+	30	29	<i>A. s. scutellaris</i>	2	1
85	20/2/53	Mission Bay Transient forest pool	3	3	+	29	28	7.2	<i>A. vexans nocturnus</i>	3	1
									<i>C. sitiens</i>		
86	20/2/53	Mission Bay Large pool in lump of coral	6	2	+	25	28	7.4	<i>T. melanotensis</i>	3	2
87	21/2/53	Himatangi Transient forest pool	3	3	+	26	25	7.2	<i>A. s. scutellaris</i>	1	1
									Pigs		
88	21/2/53	Himatangi Tree hole	7	2	+	+	....	7.4	<i>T. melanotensis</i>	1	2
89	21/2/53	Mission Bay Canoe	6	3	-	+	....	6.8	<i>A. s. scutellaris</i>	1	1
90	21/2/53	Mission Bay Tree hole	7	2	+	+	....	7.2	<i>T. melanotensis</i>	3	1
91	21/2/53	Mission Bay Tree hole	7	2	+	+	....	7.0	<i>A. s. scutellaris</i>	3	1
92	21/2/53	Mission Bay Tree hole	7	2	+	+	....	6.8	<i>A. c. jaccheli</i>	3	1
93	22/2/53	Mission Bay Brackish water in canoe	11	2	+	÷	....	7.4	<i>C. sitiens</i>	3	2
									<i>T. melanotensis</i>	2	
									<i>A. c. vestellarius</i>		
94	23/2/53	Anengauhat	9	3	÷	+	25	26	<i>An. farauti*</i>	3	2
		Brackish pond	10	2	-	+	25	25	<i>C. annulirostris*</i>	1	4
95	23/2/53	Anengauhat	6	1	-	-	28	25	<i>A. s. vestellarius</i>	1	2
96	25/2/53	Anengauhat	6	1	-	-	28	25	<i>C. pipiens fatigans</i>	1	1
97	25/2/53	Anengauhat 44 gallon drum	6	1	-	+	27	25	<i>T. melanotensis</i>	3	1
98	25/2/53	Anengauhat Truck tyre	6	1	-	+	27	25	<i>C. pipiens fatigans</i>	3	2
99	26/2/53	Anengauhat Slit in buttress	7	2	÷	+	....	7.0	<i>T. melanotensis</i>	3	2
		root									

ANEITYUM, NEW HERRIDES  
10/10 floating cover of  
pumice

TABLE I.—Continued.  
PHYSICAL AND CHEMICAL  
FACTORS

Number	Date	Collector	Locality	Bottom	Volume of bottom water	Shade	Temperature at water	pH	Microfauna	REMARKS		
										Chlorophyll bottom water	Foulness	Sp. species
100	26/2/53	ANUGAUCHAT	7	2	+	23	24	..	<i>T. melanostomis</i>	3	1	3
		Pitted coconut shell	7	1	+	26	24	8.0	<i>A. t. scutellaris</i>	1	1	1
101	26/2/53	ANUGAUCHAT	7	1	+	26	24	..	<i>T. melanostomis</i>	3	1	1
102	26/2/53	ANUGAUCHAT	7	1	—	26	24	7.8	<i>T. melanostomis</i>	1	1	1
103	27/2/53	ANUGAUCHAT	1	3	—	24	26	7.0	<i>A. farauti</i>	3	2	2/10 <i>Spirodelta</i> ploustoni
		Taro irrigation	1	3	—	24	26	7.0	<i>C. annulirostris</i>	3	4	2/10 <i>Spirodelta</i> ploustoni
104	27/2/53	ANUGAUCHAT	1	3	—	24	26	7.4	<i>A. farauti</i>	3	2	1/10 <i>Spirodelta</i> ploustoni
		Taro irrigation	1	3	—	24	26	7.4	<i>C. annulirostris</i>	1	1	1
105	1/3/53	POOR PATRICK	1	3	—	..	..	7.2	<i>A. farauti</i>	3	2	2
		Taro irrigation	9	2	+	..	..	..	<i>C. annulirostris</i>	1	1	1
106	1/3/53	POOR PATRICK	Brackish pond	9	2	+	..	..	<i>C. annulirostris</i>	3	2	1 Pigs
107	1/3/53	POOR PATRICK	Brackish pond	9	2	—	..	..	<i>A. farauti</i> *	1	1	1
108	1/3/53	POOR PATRICK	44 gallon drum	6	1	—	..	..	<i>C. annulirostris</i>	3	1	1
		Large hole in boulder	6	3	—	..	..	..	<i>A. s. scutellaris</i>	3	1	1
109	1/3/53	POOR PATRICK	Whaling try pot	6	2	+	..	..	<i>T. melanostomis</i>	3	1	1
		Large hole in boulder	6	2	+	29	27	6.8	<i>A. pernotatus</i>	2	1	1
110	1/3/53	ANUGAUCHAT	Spring-fed rock-surrounded pool	6	2	+	..	..	<i>C. annulirostris</i>	3	1	1 Thick bottom cover of decomposing leaves,
111	5/3/53	ANUGAUCHAT	Large hole in boulder	6	2	+	29	27	<i>A. t. scutellaris</i>	1	2	2
112	5/3/53	ANUGAUCHAT	Road rut	6	2	+	29	27	<i>C. p. latigena</i>	3	1	1
113	5/3/53	ANUGAUCHAT	Road rut	6	1	—	31	29	<i>A. t. scutellaris</i>	1	2	2
114	7/3/53	ANUGAUCHAT	Road rut	3	3	+	27	26	<i>A. texanus nocturnus*</i>	3	1	1 Dogs, poultry

AITUTAKI, COOK ISLANDS									
115 14/3/53	AIRFIELD	2	3	...	+	27	27	8.2	<i>C. annulirostris</i>
116 14/3/53	Marsh	1	3	+	+	30	29	8.0	<i>C. annulirostris*</i>
117 14/3/53	Borrow pit	1	3	+	—	31	29	7.4	<i>C. annulirostris*</i>
118 11/3/53	URIAKA	1	3	+	+	31	29	8.0	<i>C. annulirostris</i>
119 14/3/53	URIAKA	5	3	+	+	28	29	6.6	<i>C. annulirostris*</i>
120 14/3/53	URIAKA	6	2	+	+	...	...	7.2	<i>C. pipiens fatigans</i>
	Metal tank sunk into ground								<i>A. polynesiensis</i>
121 15/3/53	AIRFIELD	1	3	—	+	30	29	8.0	<i>C. annulirostris</i>
122 15/3/53	Borrow pit								<i>C. annulirostris</i>
123 15/3/53	TAKOKO TU	1	3	—	+	32	30	5.8	<i>C. annulirostris</i>
	Tako irrigation								<i>C. annulirostris</i>
	Brackish water in drainage								<i>C. pipiens fatigans</i>
124 15/3/53	TAKOKO TU	5	3	—	+	31	29	7.4	<i>C. annulirostris</i>
	Flowing stream								<i>C. annulirostris</i>
125 16/3/53	NKAURUA	6	1	...	+	...	...	6.8	<i>A. polynesiensis</i>
126 16/3/53	41 gallon drum	6	1	—	+	...	...	6.8	<i>A. polynesiensis</i>
127 16/3/53	NKAURUA	6	1	—	+	...	...	6.8	<i>A. polynesiensis</i>
128 16/3/53	Whaling try pot	7	2	—	+	...	...	6.8	<i>A. polynesiensis</i>
129 16/3/53	Hole in log	6	1	—	+	...	...	6.8	<i>A. polynesiensis</i>
130 16/3/53	Recurrent	6	1	—	+	...	...	7.2	<i>C. pipiens fatigans</i>
131 16/3/53	44 gallon drum	6	1	—	+	...	...	7.0	<i>A. polynesiensis</i>
	AIRFIELD	6	1	—	+	...	...	7.0	<i>A. polynesiensis</i>
	Truck tyre								<i>C. pipiens fatigans</i>
UPOLU, WESTERN SAMOA									
132 18/3/53	FALFALA AIRFIELD	6	1	—	+	26	27	6.6	<i>A. polynesiensis</i>
133 18/3/53	KEROGENE in FALFALA AIRFIELD	6	2	—	+	27	28	...	<i>C. pipiens fatigans</i>
134 18/3/53	Latitude can jeep petrol can	6	2	—	+	27	28	...	<i>A. polynesiensis</i>

TABLE I.—Continued.  
PHYSICAL AND CHEMICAL FACTORS BIOLOGY

No.	Collection Date	Habitat and Habitat Category	Water Temperature	Shade	Bottom Porousness	Nature Bottom	Pill Temperature	Species	Mosquito Abundance	Index	Pig Abundance	Index	REMARKS	
													Day	Night
135	18/3/53	FARCTIA AREFIELD	8	—	+	25	28	7.0	A. semonius	3	1	1		
136	18/3/53	Colocasia sp. <sup>8</sup>	6	—	+	26	29	7.4	C. pipiens fatigans	3	1	1		
137	18/3/53	FARCTIA AREFIELD	8	—	+	—	—	—	A. semonius	3	1	1		
		Leaf axil, <i>Alocasia</i> <i>macrorhiza</i> Schott												
138	21/3/53	LEKS	10	3	—	35	25	8.4	G. annulirostris	1	3	2	5/10 floating algal mat	
139	21/3/53	Salt marsh	1	3	—	35	25	7.4	G. annulirostris	3	2	2		
140	22/3/53	FAOUOT	1	3	—	26	27	7.4	G. annulirostris	2	3	2	Submerged algal masses	
141	22/3/53	FAOUORE	1	3	+	25	24	7.0	G. annulirostris*	2	3	2	Submerged algal masses, pigs	
142	23/3/53	Sr. Joseph	9	3	+	26	24	8.2	G. annulirostris*	3	2	2	Pigs	
143	23/3/53	Sr. Joseph	10	3	+	25	24	8.4	G. annulirostris*	3	2	2	Pigs	
144	23/3/53	Salt marsh	10	3	—	21	25	8.0	G. annulirostris	2	2	2	Submerged algal masses	
145	23/3/53	Sr. Joseph	9	3	+	28	25	8.2	G. annulirostris	1	2	2	Submerged algal masses	
146	23/3/53	Brackish pond	10	2	—	28	26	8.2	G. annulirostris	1	3	2	Submerged algal masses	
147	23/3/53	Sr. Joseph	9	3	+	28	26	7.6	C. pipiens fatigans*	2	2	1	Pigs	

The common cultivated taro of the Pacific. Some botanists recognize two distinct species, *C. esculenta* (L.) and *C. antiquorum* Schott, others only one (Mastal, Li, and Barrau, 1945). *Quart. Bull. South Pacific Commission*, 5 (2), 17-22.

TABLE I.—Continued.  
PHYSICAL AND CHEMICAL  
FACTORS

Collection number	Date	Locality and habitat	BIOLOGY			REMARKS
			Number of adults	Number of nymphs	Number of eggs	
164	18/6/53	Ara, tree hole	7	1	—	+ 33 27 6.8 <i>C. pipiens fatigans</i>
165	18/6/53	Tin can	6	1	—	+ 25 27 7.0 <i>A. aegypti</i>
166	18/6/53	44-gallon drum	6	1	—	+ 25 26 6.8 <i>A. aegypti</i>
167	18/6/53	Ara, truck tire	7	1	—	+ 25 26 8.0 <i>A. polynesiensis</i>
168	18/6/53	Ara, tin can	8	1	—	+ ... ... 6.6 <i>A. samoanus</i>
169	18/6/53	Leaf axil, <i>Alocasia macrothalia</i>	7	2	—	+ 27 26 7.6 <i>A. samoanus</i>
170	18/6/53	Ara, tree hole	1	3	+	— 30 26 7.4 <i>C. annulirostris</i> *†
171	18/6/53	Taro irrigation	1	3	+	+ 32 27 6.6 <i>A. texanus nocturnus</i>
172	18/6/53	Small seepage pond	3	2	+	+ 29 27 7.4 <i>C. annulirostris</i> *†
173	18/6/53	Ara, transient pool fed by dripping tap	8	1	—	+ 29 27 7.0 <i>A. samoanus</i>
174	18/6/53	Ara, leaf axil, <i>Colocasia</i> sp.	7	1	—	+ 28 27 ... <i>A. polynesiensis</i>
175	19/6/53	Tin can	11	1	—	+ 26 27 7.4 <i>C. sitiens</i>
176	19/6/53	Brackish water in canoe	4	3	+	— 34 27 8.2 <i>C. annulirostris</i> *†
177	19/6/53	Ara, ponded ditch	7	2	—	+ 26 27 8.0 <i>A. polynesiensis</i>
		Tree hole				

Mosquito abundance index  
Prairie index

Spores index

Microspores index

Temperature after 1 P.M.

Relative humidity

pH

Atmospheric pressure

Wind force

Cloudiness

UPOLU, WESTERN SAMOA



TABLE I.—Continued.  
PHYSICAL AND CHEMICAL  
FACTORS

	Date	Collector	Habitat	Locality and Habitat	Number of	Chargarty	Volume of	Poultiness	Water temperature	Moisture	Moisture index	Abundance	Insecticide	Shade	Temperature	Humidity	Remarks
193	18/7/53	LUCANVILLE	Concrete floor of abandoned shed	Lucanville	6	1	+	+ 23	23	3.4	C. <i>pipiens fatigans</i>	2	1	1	Domestic animals		
194	18/7/53	LUCANVILLE	Truck tire	Lucanville	6	1	—	+ 25	23	6.3	A. <i>s. scutellaris</i> C. <i>pipiens fatigans</i>	3	2	1			
195	22/7/53	KURUM	Road rut	GUADALCANAL, BRITISH SOLOMON ISLANDS PROTECTORATE	3	3	—	+ 35	29	8.4	A. <i>lineat.</i> C. <i>annulirostris</i> †	2	2	2	4/10 floating algal mat		
196	22/7/53	ITONIMA	Floating stream	ITONIMA	5	4	—	+ 27	28	7.8	An. <i>punctulatus</i> C. <i>squamatus</i>	1	2	2	6/10 floating algal mat		
197	24/7/53	TIN CAN	Floating stream	ITONIMA	7	1	—	+ 29	26	7.2	C. <i>pipiens fatigans</i>	2	1	1			
198	27/7/53	KURUM	Tin can	ITONIMA	3	3	+	+ 32	27	7.8	C. <i>haematoxalis</i> * C. <i>annulirostris</i> *	3	2	1	Pigs		
199	28/7/53	ITONIMA FIELD	Road rut	ITONIMA FIELD	1	3	—	+ 35	30	9.5	An. <i>punctulatus</i> C. <i>annulirostris</i>	1	2	2	9/10 bottom algal cover		
200	28/7/53	ITONIMA FIELD	Roadside drainage	ITONIMA FIELD	3	3	+	+ 32	27	7.4	An. <i>irroratus</i> An. <i>lineatum</i> *	2	2	1	Cattle		
201	28/7/53	IUA FARM	Hoofprint	IUA FARM	3	3	+	+ 33	27	7.2	C. <i>annulirostris</i> * C. <i>lineatum</i> *	2	2	1	Pigs		
202	28/7/53	IUA FARM	Transient pool in pig wallow	IUA FARM	5	3	—	+ 30	27	7.4	B. <i>hollandi</i>	1	..	2			
203	29/7/53	POHA R. MOUTH	Ponded river	POHA R. MOUTH	4	3	—	+ 29	26	6.6	An. <i>punctulatus</i> An. <i>jarau</i>	3	2	2	1/10 floating algal mat		
204	29/7/53	POHA R. MOUTH	Ponded river	POHA R. MOUTH	4	3	—	+ 29	26	6.6	B. <i>hollandi</i> An. <i>punctulatus</i> An. <i>jarau</i>	2	1	2	1/10 floating algal mat		
205	29/7/53	POHA R. MOUTH	Flowing stream	POHA R. MOUTH	5	4	—	+ 28	26	6.4	C. <i>squamatus</i> An. <i>jarau</i>	2	2	2	Submerged algal masses		



TABLE I.—Continued.  
PHYSICAL AND CHEMICAL FACTORS IN BIOLOGY

Collector's Number	Habitat	Quality of water	Depth or bottom	Poultiness	Shade	Temperature of water	pH	Air temperature	Water hardness	Mosquitoes	Spiders	Arthropods	Families	Abundance of families	Relative index	REMARKS	
222	7/8/53 HILLTOP, 914m Leaf axil, member of Pandanaceae	8	2	+	22	23	6.6	<i>Corythella</i> sp.						1	1	1	
223	7/8/53 TAKAMU, 931m Leaf axil, 931m	8	2	—	21	23	6.6	<i>T. mathesoni</i>						1	2	2	
224	7/8/53 COLAQUER SP. TALAXAO, 914m Ponded stream	4	4	—	19	20	6.8	<i>An. solomonis</i>						1	2	1	
225	8/8/53 SAVASARAKAMA, 911m Fallen palm, spathe	7	2	—	+	...	...	<i>U. quadrinotata</i>						3	1	1	
226	8/8/53 HILLTOP, 837m Transient forest pool	3	2	+	+	22	23	...	<i>C. pauperculus</i>					3	2	2	
227	8/8/53 TONI R., 143m Ponded stream	4	4	—	—	26	7.2	<i>C. siamensis</i>						3	2	2	
228	9/8/53 TONI R., 125m Ponded stream	4	4	—	—	24	7.2	<i>An. punctulatus</i>						3	2	2	
								<i>G. annulivittatus</i>						3	2	2	
								<i>C. pulchellus</i>						2	2	2	
								<i>C. halifexi</i>						1			
229	15/8/53 AHANGA Canyon	11	1	+	26	25	7.4	<i>A. s. scutellaris</i>						3	1	1	BELLONA, BRITISH SOLOMON ISLANDS PROTECTORATE
230	15/8/53 AHANGA Canyon	6	1	+	26	25	7.4	<i>A. s. scutellaris</i>						3	1	1	
231	15/8/53 MATHEXTA Dug-out water container	6	2	—	+	26	26	6.8	<i>C. fraudatrix</i>					3	2	1	
232	15/8/53 AHANGA MATAHINA Large pool in coral boulder	6	2	+	26	27	7.4	<i>C. fraudatrix</i>						2	2	1	
233	15/8/53 MATHEXTA 44 gallon drum	6	1	—	+	28	27	6.6	<i>A. thalassius</i>					1	1	1	

234	15/8/53	MATAENIA	7	1	-	+ 29	7.2	<i>A. s. scutellaris</i>	3	1	1	
		Half coconut shell										
		LONGONA	6	2	+	+ 26	6.6	<i>A. s. scutellaris</i>	3	1	1	
		Tyre from wrecked aircraft										
236	16/8/53	LONGONA	6	2	-	+ 26	6.6	<i>A. s. scutellaris</i>	2	1	1	
		44 gallon drum										
237	16/8/53	HANGAMAGAMA	7	2	+	+ 25	6.6	<i>C. fraudatrix</i>	3	2	1	
		Tree hole										
238	17/8/53	ARANGA	11	2	+	+ 26	7.4	<i>C. fraudatrix</i>	3	2	1	
		Brackish water in cance										
								<i>A. albidaeatus</i>	2			
								<i>A. albidaeatus</i>	2			
239	18/8/53	LAVANGOU	7	3	-	+ 24	7.0	<i>A. s. scutellaris</i>	1	1	1	RENNELL, BRITISH SOLOMON ISLANDS PROTECTORATE
		Half coconut shell										
240	18/8/53	LAVANGOU	7	1	-	+ 24	7.0	<i>A. s. scutellaris</i>	2	1	1	
		Half coconut shell										
241	18/8/53	LAVANGOU	7	3	-	- 26	7.0	<i>A. s. scutellaris</i>	3	1	1	
		Half coconut shell										
242	18/8/53	LAVANGOU	7	2	-	+ 24	7.0	<i>A. albidaeatus</i>	3	2	1	
		Small pool in coral crevice										
243	18/8/53	LAVANGOU	11	1	-	+ 25	8.0	<i>A. s. scutellaris</i>	3	1	1	
		Brackish water in cance										
244	18/8/53	LAVANGOU	7	2	+	+ 25	7.0	<i>A. albidaeatus</i>	3	1	1	
245	18/8/53	LAVANGOU	7	2	+	- 27	7.4	<i>A. s. scutellaris</i>	1	1	1	
246	18/8/53	LAVANGOU	11	1	+	+ 25	9.5	<i>A. s. scutellaris</i>	1	1	1	
		Pool in coral just above high water mark										
247	18/8/53	LAVANGOU	6	2	-	+ 25	7.2	<i>C. fraudatrix</i>	3	2	1	
248	18/8/53	LAVANGOU	6	2	+	+ 26	7.6	<i>A. s. scutellaris</i>	3	1	1	
		Rock-surrounded springs-fed pool						<i>C. fraudatrix</i>	2			
249	18/8/53	LAVANGOU	6	2	+	+ 26	7.2	<i>A. s. scutellaris</i>	3	2	1	
		Rock-surrounded springs-fed pool						<i>A. albidaeatus</i>	3			
250	19/8/53	NUNANI, LAKK.	9	3	+	- 30	7.8	<i>C. annandrois†</i>	3	4	2	Some faecal contamination, submerged at high tides
		Edge of brackish lake						<i>C. squamans</i>	2			
								<i>An. farauti</i>	1			

TABLE I.—Continued.  
PHYSICAL AND CHEMICAL FACTORS BIOLOGY  
REMARKS

Number Date	Location	Soil type	Altitude feet	Latitude of parallel	Distance from coast	Category of soil	Soil depth inches	Soil texture	Soil pH	Water table	Temperature Air Temp. °F.	Relative humidity	Species present	REMARKS			
														Mosquitos	Arthropods	Others	
231 19/8/53	Niu Farm Rut-gravved coconut orchard surrounded by spring-fed pool	1f. Urticaceous soil	7	2	+	—	—	—	—	—	25	24	7.2	<i>A. a. scutellaris</i>	1	2	1
252 20/8/53	SAVO, BRITISH SOLOMON ISLANDS PROTECTORATE	6	2	+	+	—	—	—	—	—	—	—	—	<i>A. a. scutellaris</i>	3	2	1
253 23/8/53	OXMALA CALIX	5	4	—	+	—	—	—	—	—	34	26	7.4	<i>An. punctulatus</i>	2	1	1
254 23/8/53	OXMALA CREEK	5	3	—	—	—	—	—	—	—	hot earth of thermal area	—	—	<i>An. punctulatus</i>	2	1	1
255 2/9/53	Iru Farm 44 gallon drum-	Lrg. pond in pig wallow	1	3	+	26	27	7.2	C. annulirostris*	—	30	26	7.4	<i>C. annulirostris*</i>	3	2	1
256 2/9/53	Iru Farm Large pond in pig wallow	5	4	—	—	—	—	—	—	—	7.0	<i>An. punctulatus</i>	—	2	1	Pigs	
257 2/9/53	Iru Farm Buckwater of stream	3	—	—	—	—	—	—	—	—	7.2	<i>C. pallidus</i>	—	1	—	—	
258 2/9/53	Iru Farm Hoofprint	3	2	—	+	26	24	7.4	<i>A. lineatus</i>	—	—	—	—	—	—	—	
259 3/9/53	Iru Farm Forest pool	3	3	+	—	—	—	—	—	—	—	—	—	<i>U. cinnamini</i> *	3	1	1
260 3/9/53	Iru Farm Hoofprint	3	3	+	—	—	—	—	—	—	—	—	—	<i>U. cinnamini*</i> *	3	2	1
261 3/9/53	Iru Farm Hoofprint	3	3	+	—	—	—	—	—	—	—	—	—	<i>U. cinnamini*</i>	1	2	1
														<i>U. cinnamini</i>	1	—	—
														<i>G. halifaxi</i> *	1	—	—

262	3/9/53	Iru Farm Hoofprint	3	3	+	24	25	7.2	<i>C. hortulaxi*</i>	1	1	Cattle, horses	
263	3/9/53	Iru Farm Hoofprint	3	3	+	24	25	7.2	<i>C. philipes</i> *† <i>U. cinnamomea</i> *† <i>U. hawaiiensis</i> *†	3	2	Cattle, horses	
264	3/9/53	Iru Farm Transient pool in grassy hollow	3	2	+	—	26	25	7.0	<i>C. fumiferana</i> *† <i>U. ciliatissima</i> *† <i>U. volvulus</i> *†	1	2	Cattle, horses
265	3/9/53	Iru Farm Hoofprint	3	2	+	—	26	25	7.4	<i>C. philipes*</i>	3	2	Cattle, horses
266	4/9/53	Hedgerow Field 11 Brackish water in hulk	1	1	—	+	30	27	7.0	<i>C. annulirostris</i>	2	2	
267	4/9/53	Hedgerow Field 10 Edge of tidal marsh	3	—	+	31	27	8.2	<i>An. farauti*</i>	1	2		
268	5/9/53	Iru Farm Ponded stream	4	3	—	+	26	27	7.0	<i>C. annulirostris</i>	2	3	Cattle, horses
269	5/9/53	Iru Farm Flooded ditch	4	3	+	—	26	25	7.2	<i>An. farauti*</i>	1	2	Cattle, horses
270	5/9/53	Iru Farm Ponded ditch	4	2	—	+	26	25	7.2	<i>An. punctulatus</i>	1	1	
271	5/9/53	Iru Farm Road rut	3	3	+	—	31	26	7.2	<i>B. holoserici</i>	3	2	Cattle, horses
272	6/9/53	Iru Farm Hoofprint	3	3	+	—	25	24	7.2	<i>C. annulirostris</i>	3	1	Cattle, horses
273	6/9/53	Iru Farm Hoofprint	3	3	+	—	25	24	7.2	<i>An. farauti*</i>	2	2	Cattle, horses
274	6/9/53	Iru Farm Hoofprint	3	3	+	—	26	24	7.2	<i>C. philipes</i>	1	2	Cattle, horses
275	6/9/53	Iru Farm 4½ gallon drum	6	1	—	+	25	25	7.0	<i>C. philipes</i>	3	1	
276	6/9/53	Iru Farm 4½ gallon drum	6	1	—	—	28	26	7.4	<i>C. annulirostris*</i> <i>C. philipes*</i> <i>An. farauti*</i>	2	2	
277	10/9/53	Lunga R. Mouth	4	3	—	—	29	25	9.2	<i>C. hortulaxi*</i>	1	3	Pond filled with a mass of submerged vegetation (un- identified)
278	10/9/53	Pr. Cruz Brackish water in tire	11	3	—	+	29	25	8.2	<i>C. sitiens</i>	3	2	1

TABLE I.—*Continued.*  
PHYSICAL AND CHEMICAL FACTORS  
BIOLOGY  
REMARKS

TONGATAPU, TONGA									
291	26/10/53	Nukut'ALOFA Sepate pond	1	3	—	38	22	4.0	<i>A. vexans nocturnus</i>
292	26/10/53	O.L.A. O.L.A. Pond in excavation	1	3	+	32	22	8.0	<i>C. annulirostris</i> †
293	26/10/53	O.L.A. O.L.A. Leaf axil,	8	1	+	24	22	7.0	<i>A. vexans nocturnus</i>
294	26/10/53	F.N.S.A. U.R.A. Lagoon	4	2	+	22	23	7.4	<i>A. vexans nocturnus</i> *
295	26/10/53	F.N.S.A. U.R.A. Brackish pond	9	3	—	36	23	8.0	<i>C. annulirostris</i>
296	26/10/53	F.N.S.A. U.R.A. Lagoon	9	3	—	36	23	8.0	<i>C. annulirostris</i>
297	26/10/53	Nuku Alofa, Bottom of large concrete tank sunk into ground	6	1	+	—	—	9.5	<i>C. pipiens fatigans</i>
VITI LEVU, FIJI									
298	29/11/53	Natismasi	6	2	+	31	27	7.6	<i>C. annulirostris</i>
299	15/12/53	Deep pot hole in rock platform	—	—	—	28	25	6.4	<i>C. annulirostris</i>
300	15/12/53	NABUKAVESTI Creek	3	3	—	—	—	—	—
301	27/12/53	Flowing stream	5	4	—	—	—	—	—
302	27/12/53	Wainavest R.	3	3	+	27	24	6.2	<i>C. annulirostris</i>
303	27/12/53	Illoprint R.	1	3	+	27	24	6.8	<i>C. annulirostris</i> †
304	28/1/54	Wainavest R. Large deep pond	6	1	—	28	24	7.4	<i>C. albivertis</i>
305	28/1/54	Pot hole in rock platform	—	—	—	—	—	—	—
TARAWA, GILBERT ISLANDS									
306	28/1/54	Burkett Small transient	3	3	—	—	—	—	—
307	28/1/54	Tronaerucker Brackish pond	9	3	—	29	27	8.0	<i>C. annulirostris</i>

TABLE I.—Continued.  
BIOLOGY  
PHYSICAL AND CHEMICAL  
FACTORS

Collection Number	Date	Locality	Habitat	Number of specimens	Degree of naturalization	Shade	Temperature	Relative humidity	Species	Abundance	Index	REMARKS			
												Index			
306	28/1/54	Teakoreake Flooded crab hole	12	3	+	+	27	28	<i>C. annulirostris</i>	3	2	1			
307	28/1/54	Taoralarake Taro pond	1	2	—	+	29	28	<i>C. annulirostris</i>	2	1	2			
308	28/1/54	Teakoreake Half coconut shell	7	1	—	+	27	28	<i>A. marshallensis</i>	3	1	1			
309	29/1/54	Bira Taro pond	1	3	—	+	31	29	<i>C. annulirostris</i>	3	2	2			
310	28/1/54	Biraki Taro pond	1	3	—	+	30	28	<i>A. vexans nocturnus</i>	1	2	2			
311	29/1/54	Ord Airstrip Small transient pool	3	3	—	+	32	29	<i>A. vexans nocturnus</i>	2	2	1			
312	29/1/54	Ord Airstrip Taro pond	1	3	—	—	37	29	<i>A. vexans nocturnus</i>	3	2	2			
313	29/1/54	Virae Crab in lump of coral	7	2	—	+	28	29	<i>C. annulirostris</i>	2	1	1			
314	29/1/54	Virae Ord coconut shell	7	1	—	+	28	29	<i>A. polynesiensis</i>	3	1	1			
315	29/1/54	Virae ½ gallon drum	6	1	—	+	30	29	<i>A. polynesiensis</i>	3	1	1			
									<i>A. aegypti</i>	2					
316	1/3/54	Gates Pool, Savu,	8	2	+	+	23	25	<i>A. (Finlaya) sp.</i>	1	2	1			
		Leaf axil, <i>Ficus</i> <i>elastica milnei</i>													
317	1/3/54	Gates Pool, Savu, Cut stem of wild banana	7	2	+	+	23	25	<i>T. purpurea</i>	2	2	1			
									<i>A. pseudoscelistella</i>	1					

318	8/3/54	NANDARAVATU, 1000m Leaf axil, <i>Frey- cinetia milnei</i>	8	2	+	20	21	6.8	<i>A. (Finlaya) sp.</i>	1	2	1	
319	8/3/54	NANDARAVATU, 850m Leaf axil, <i>Frey- cinetia milnei</i>	8	2	+	20	21	6.8	<i>A. (Finlaya) sp.</i>	1	2	1	
320	9/3/54	NANDARAVATU, 686m Road rut	3	3	+	29	23	6.6	<i>A. texanus nocturnus</i>	1	2	2	
321	9/3/54	NANDARAVATU, 686m Large pond in hollyhock hollow	1	3	+	22	24	6.8	<i>C. annulirostris*</i>	1	3	2	
322	9/3/54	NANDARAVATU, 686m Road rut	3	3	+	29	24	6.8	<i>A. texanus nocturnus</i>	3	2	1	
323	9/3/54	NANDARAVATU, 686m Holopoint	3	3	+	29	25	6.6	<i>C. annulirostris</i>	1	2	2	
324	9/3/54	NANDARAVATU, 672m Leaf axil, <i>Frey- cinetia milnei</i>	8	2	+	24	25	7.2	<i>A. (Finlaya) sp.</i>	1	2	1	
325	10/3/54	NANDARAVATU, 630m Tree hole	7	2	-	19	20	7.2	<i>T. purpurea</i>	3	1	1	
326	5/6/54	HOLLOWAY BRANCH R.R., Cairns Roadside seepage pond	1	3	+	-	19	16	6.8	QUEENSLAND, AUSTRALIA	3	3	2
327	5/6/54	HOLLOWAY BRANCH R.R., Cairns Roadside seepage	1	3	-	+	19	17	5.8	<i>An. farauti</i>	3	3	2
328	6/6/54	MOSMAN Ponded stream	1	2	--	--	23	22	6.2	<i>C. cylindricus</i>	2	3	2
329	6/6/54	MOSMAN Borrow pit	1	3	--	-	29	23	6.2	<i>C. fumiferus</i>	2	2	2
330	6/6/54	MOSMAN Roadside seepage	1	3	-	+	26	23	7.0	<i>C. annulirostris</i>	1	2	3
									<i>Aj. cestata</i>	1			

TABLE I.—Continued.  
PHYSICAL AND CHEMICAL  
FACTORS

Collection Number	Date	Locality and Habitat	BIOLOGY			REMARKS
			Bottom of Stream	Shade	Water Temperature	
331	7/6/54	Yorkin's Knob Salt marsh	(u)	—	+ 27 24 8.0	<i>C. siensis</i> <i>A. vigilax</i>
332	7/6/54	Yorkin's Knob Borrow pit	1	-	+ 23 24 6.4	<i>An. b. bancroftii</i> <i>C. annulirostris</i> <i>C. cylindraceus</i>
333	8/6/54	Broughan's Point, Cairns	9	—	+ 25 22 7.4	<i>A. vigilax</i> <i>An. farauti</i> <i>C. siensis</i>
334	8/6/54	Highway just S. or Bichan's Pr.	4	—	+ 22 21 6.6	<i>An. annulipes</i> <i>A. alternans</i>
335	8/6/54	Highway just S. of Bichan's Pr.	4	—	+ 22 21 7.4	<i>C. whitmorei</i> <i>C. cylindraceus</i> <i>C. annulirostris†</i> <i>An. farauti</i> <i>C. helvata</i>
336	8/6/54	Palm Cove	1	3	+ 22 21 6.2	<i>C. whitmorei</i> <i>C. cylindraceus</i> <i>C. annulirostris†</i> <i>An. farauti</i> <i>U. atra</i> <i>C. minimus</i>
337	9/6/54	Civt. AIRFIELD, Cairns	10	2	+ 21 20 7.4	<i>C. annulirostris</i>
338	9/6/54	Mangrove swamp, Civt. AIRFIELD, Cairns	10	3	+ 24 20 9.0	<i>C. annulirostris</i>
339	9/6/54	Mangrove swamp, Civt. AIRFIELD, Cairns	9	3	+ 21 20 7.4	<i>C. annulirostris</i> <i>An. farauti</i>
340	9/6/54	Brackish pond, Civt. AIRFIELD, Cairns	9	3	— 23 20 8.4	<i>C. siensis</i>
		Brackish pond				Cattle, 3/10 <i>Lemna plaeon</i>

341	9/6/54	Civr. AIRFIELD, CAIRNS Brackish pond	9	3	-	23	19	9.5	<i>Ay. cataphacta</i>	3	3	2	Submerged algal masses throughout	
342	9/6/54	Civr. AIRFIELD, CAIRNS Brackish pond	9	3	-	23	19	7.8	<i>Ay. cataphacta</i>	1	2	2	Submerged eucalypt rootlets to one side	
343	10/6/54	GORDONVALS Road rut	3	3	+	23	20	9.5	<i>C. annulirostris</i> *†	3	2	1	Wallabies	
344	10/6/54	GORDONVALS Road rut	3	3	+	23	20	8.0	<i>C. annulirostris</i>	3	2	1	Wallabies	
									<i>A. alobionotatus</i>	3				
									<i>A. farauti</i> ‡	2				
									<i>A. annulipes</i> §	2				
									<i>C. halifex</i> ¶	2				
									<i>A. albostriatus</i>	1				
345	11/6/54	COOK HIGHWAY just N. of Buchan's Pr.	9	2	+	22	21	6.2	<i>An. farauti</i>	1	4	1		
									<i>C. annulirostris</i>	1				
346	11/6/54	CASCADE CREEK, Cook HIGH- WAY	6	2	+	21	18	7.2	<i>C. halifex</i> *	2	2	1	Wallabies	
		Pot hole in rock sheet							<i>C. halifex</i>	1				
347	11/6/54	COOK HIGHWAY, just N. or Buchan's Pr.	4	2	..	4	19	18	<i>An. annulipes</i>	2	2	1		
		Ponded stream							<i>C. halifex</i>	1				
348	11/6/54	HIGHWAY just S. of Buchan's Pr.	5	3	+	-	25	18	<i>An. annulipes</i> *	2	2	2	Submerged algal masses throughout, cattle	
		Ponded stream							<i>C. bauinictus</i>	2				
349	11/6/54	HIGHWAY just S. of Buchan's Pr.	4	3	-	+ 21	18	8.2	<i>C. quadrimaculatus</i>	3	3	2	Submerged algal masses throughout	
		Ponded stream							<i>C. hispanicus</i>	3				
									<i>An. farauti</i>	2				
									<i>C. whitmorei</i>	2				
									<i>U. atra</i>	1				
									<i>An. b. bancroftii</i> †	3	3	2	Cattle, horses	
									<i>An. annulipes</i> †	3				
350	12/6/54	ATIRIBROS, 600m large pond in ratte paddock	1	3	+	-	22	13	8.2	<i>An. b. bancroftii</i> †	2	2	2	Cattle, horses
351	12/6/54	ATIRIBROS, 600m Marsh	2	3	+	-	24	13	6.8	<i>An. annulipes</i> †	2	2	2	Cattle, horses
									<i>C. annulirostris</i>	2				

TABLE I.—Continued  
PHYSICAL AND CHEMICAL FACTORS  
BIOLOGY

Date	Collection Number	Locality and Habitat	Bottom Temperature	Water Depth	Water Temperature	PHT	Species	Abundance	Relative Index	Remarks	
12/6/54	352	Scourvy Cull, Antarctica, 600m	1	+	19	13	6.0	<i>An. b. baueri</i> † <i>An. stigmatulus</i>	2	3	Cattle
13/6/54	353	Krasava, 300m Ponded stream	4	2	—	18	15	<i>C. fraudatrix</i>	1	1	
13/6/54	354	Krasava, 300m Roadside seepage pond	1	3	—	19	15	<i>An. annulipes</i> <i>An. farauti</i>	1	3	2
13/6/54	355	MAREBA, 400m Ponded stream	4	4	+	17	20	<i>C. annulirostris</i> <i>C. whitmorei</i>	2	2	Cattle
13/6/54	356	MAREBA, 400m Roadside seepage pond	1	3	+	22	20	<i>C. annulirostris*</i> <i>C. whitmorei</i>	2	1	
13/6/54	357	MAREBA, 400m Ponded stream	4	2	+	19	20	<i>C. annulirostris*</i> <i>C. fraudatrix*</i>	2	3	Wallabies
13/6/54	358	MAREBA, Forest pond	1	2	+	19	16	<i>C. annulirostris*</i> <i>C. minuta*</i>	1	2	Cattle
14/6/54	359	INTERVAL Seepage pond in cattle paddock	1	3	—	24	19	<i>C. fraudatrix*</i> <i>C. minuta*</i> <i>An. farauti*</i> <i>C. hispanetus</i>	2	3	Submerged algal masses
15/6/54	360	RUSSELL R., NEAR BANDA	4	3	—	23	21	<i>An. farauti</i>	1	3	Submerged algal masses
15/6/54	361	Laracool Creek, S. of Lantau, 1	—	—	—	26	22	<i>Aj. catasticta</i> <i>An. b. baueri</i> †	2	2	Dense growth of <i>Najas</i> throughout
16/6/54	362	TULLY Large pond	1	3	+	25	22	<i>An. farauti</i>	1	2	Rubbish dump

363	16/6/54	MURUGAI, Roadside seepage pond	1	3	+	-	23	22	7.2	<i>An. farauti</i> <i>C. annulipes*</i>	3	4	2	Cattle, submerged algal masses
364	16/6/54	Sreyu Creek, near Caudwell, Ponded stream	4	4	-	-	31	25	6.2	<i>An. annulipes</i> <i>C. basicinctus</i>	3	3	2	Submerged algal masses
365	16/6/54	ISCHAM, Flowing stream	5	3	-	+	29	25	6.6	<i>An. annulipes</i>	1	3	2	Submerged algal masses
366	17/6/54	LAUCHAM, Road side pond	3	3	+	+	17	19	7.2	<i>An. annulipes</i>	2	2	1	
367	17/6/54	IRAWAR, S. of Ingaham Flowing stream	5	3	+	-	24	19	6.0	<i>An. farauti†</i> <i>An. b. bancroftii</i>	2	3	2	Cattle
368	17/6/54	IRAWAY 15km S. of Ingaham Roadside seepage	1	3	+	-	25	21	8.0	<i>C. annulirostris†</i> <i>An. annulipes</i>	3	3	2	Cattle
369	17/6/54	SIRYURUS, CRANK, RIVERFRONT, Still backwater of flowing stream	5	4	-	+	24	23	6.0	<i>C. squamosus</i> <i>C. basicinctus</i> <i>An. annulipes</i>	3	3	2	Submerged algal masses throughout
370	18/6/54	HUTIWAY 16km S. of Towns- ville Ponded stream	4	4	-	+	20	17	8.0	<i>An. annulipes</i> <i>An. b. bancroftii</i> <i>C. basicinctus</i>	3	4	2	Submerged algal masses throughout
371	18/6/54	TEONPAN CREEK, HUTIWAY 32km S. of Towns- ville	4	3	+	+	19	20	8.0	<i>An. annulipes*</i>	2	4	2	Cattle, submerged algal masses
372	18/6/54	TEONPAN CREEK Ponded stream	4	4	+	-	23	20	8.4	<i>C. annulirostris</i> <i>An. annulipes</i>	3	3	2	Cattle, submerged algal masses

TABLE II  
Summary of data from collections lacking mosquitoes.  
PHYSICAL AND CHEMICAL FACTORS

Collection Number	Date	Locality and Habitat	Category of habitat	BIOLOGY				REMARKS
				Water depth	Temperature index	pH	Relative humidity	
1 <sup>a</sup>	15/6/52	Nausori Deep pond	1    3    +    -	29	28	7.2	4    2	VITI LEVU, FIJI
2 <sup>a</sup>	2/8/52	ANELGAUHAT Forest pond	7    2    -    -	21	20	7.8	2    1	ANEITYUM, NEW HEBRIDES
3 <sup>a</sup>	15/8/52	SOUTHERN HILL. Forest pond	1    2    +    +	24	23	6.8	1    2	TUTUBA, NEW HEBRIDES
4 <sup>a</sup>	23/8/52	SOUTHERN HILL. Forest pond	1    2    +    +	23	22	6.6	2    2	10/10 <i>Spirodela</i> plateau
5 <sup>a</sup>	20/9/52	SUVA Hoofprint.	3    3    +    -	27	23	5.8	2    2	VITI LEVU, FIJI
6 <sup>a</sup>	20/9/52	DRAVINA Marsh	2    3    +    -	31	23	6.6	2    2	
7 <sup>a</sup>	20/9/52	Koroou Ponded ditch	4    3    +    +	23	22	7.4	2    1	
8 <sup>a</sup>	21/9/52	NAMO Ponded ditch	4    3    -    +	29	20	7.0	2    2	
9 <sup>a</sup>	21/9/52	NASDR Ponded ditch	4    3    +    +	25	26	7.4	2    2	
10 <sup>a</sup>	22/9/52	LAWRA Rearside seepage	1    3    +    +	22	26	7.4	3    2	
11 <sup>a</sup>	22/9/52	RASIKI Roadside seepage	1    3    +    +	28	30	8.0	3    2	Pond
12 <sup>a</sup>	26/11/52	UALA Leaf axil, <i>Pandanus</i> , sp.	8    1    -    +	26	28	7.4	2    1	ART, BELIEP ISLANDS



TABLE II.—Continued.  
PHYSICAL AND CHEMICAL BIOLOGY  
FACTORS

Collector's Number	Date	Locality and Habitat	Habitat Category of Collection	Bottom Features	Water Shade	Air Temperature	PDI	Annual Temperature Index	REMARKS		
									8	1	—
28 <sup>a</sup>	16/6/53	Virler, <i>Pandanus</i> sp.	Leaf axill.	Submerged algal masses	—	... + ...	...	...	...	...	...
29 <sup>b</sup>	18/6/53	Aria	Large rock pool	UPOIŪ, WESTERN SAMOA	6	4	—	29	26	6.3	3
30 <sup>c</sup>	6/8/53	Malauv	Concrete water trough	LAU GROUP, FIJI (T. M. Skerman, coll.)	6	2	...	+	24	25	7.4
31 <sup>d</sup>	3/8/53	Levua R., Berloneka, 262m	Ponded stream	GUADALCANAL, BRITISH SOLOMON ISLANDS PROTECTORATE	4	2	—	25	24	7.4	3
32 <sup>e</sup>	4/8/53	Berloneka, 333m	Quiet reach of flowing stream	...	5	4	—	+	26	25	7.4
33 <sup>f</sup>	5/8/53	Berloneka, Tree hole	553m	...	7	2	—	+	21	22	6.2
34 <sup>g</sup>	5/8/53	Berloneka R., Flowing	349m	...	5	4	—	+	... ...	7.0	2
35 <sup>h</sup>	5/8/53	Hurop	577m	Transient forest	3	3	—	+	22	21	6.4
36 <sup>i</sup>	6/8/53	Turamairoko, Flowing	579m	...	5	4	—	+	...	7.2	3
37 <sup>j</sup>	6/8/53	Vitavula R., Ponded	344m	...	4	4	—	+	...	7.2	2
38 <sup>k</sup>	6/8/53	Vitavula R., Large hole in boulder	344m	...	6	2	—	+	...	6.4	2

BELLONA, BRITISH SOLOMON ISLANDS PROTECTORATE									
39 <sup>1</sup>	15/8/53	Manureta Leaf axil	8	2	-	+	29	27	7.0
		<i>Colocasia</i> sp.	6	2	-	+	25	27	6.6
40 <sup>1</sup>	16/8/53	Loxovax Due-out water Container	8	2	-	+	28	27	7.0
41 <sup>1</sup>	16/8/53	Loxovax Leaf axil, <i>Pandanus</i> sp.	8	2	-	+	28	27	7.0
GUADALCANAL, BRITISH SOLOMON ISLANDS PROTECTORATE									
42 <sup>1</sup>	6/9/53	Ilu Farm Holepoint	3	3	+	+	26	24	7.2
		Pora R. Mouth	4	4	-	-	30	27	7.4
43 <sup>1</sup>	11/9/53	Ponded stream							4
SIKAIANA, BRITISH SOLOMON ISLANDS PROTECTORATE									
44 <sup>1</sup>	14/9/53	Eastern end of Island	6	1	-	+	24	25	6.8
		44 gallon drum	6	1	-	+	26	25	6.8
45 <sup>1</sup>	14/9/53	Loro Iron pot used as water butt							2
TONGATAPU, TONGA									
46 <sup>1</sup>	26/10/53	Ola Ola Forest pond	1	2	+	+	24	23	7.4
									2
47 <sup>1</sup>	8/11/53	Deviakai Pool in coral just above high water mark	11	2	-	+	27	31	7.4
		Gian Point Srv., 123m	6	2	+	-	28	22	6.2
		Pol. hole in rock plantation							2
48 <sup>1</sup>	22/11/53	Siva Point Mangrove swamp	10	2	-	+	27	26	7.0
		Gian Point Srv., 123m	5	4	-	+	27	28	7.0
49 <sup>1</sup>	1/12/53	Siva Point Mangrove swamp							2
50 <sup>1</sup>	13/12/53	Siva Point Mangrove swamp							2
51 <sup>1</sup>	15/12/53	Nanavavasi Creek	4	4	-	-	33	26	7.0
		Oxbow pond							2

TABLE II.—Continued  
PHYSICAL AND CHEMICAL FACTORS BIOLOGY

COLLECTOR	DATE	LOCALITY	HABITAT	BIOLOGY			REMARKS
				NUMBER OF INDIVIDUALS	PERCENT WATER TEMPERATURE	PERCENT SHADE	
52 <sup>a</sup>	20/12/53	GLEN POOL, SUVA, 12km S. Still backwater Wainrser R.	Leaf axil, Leaf axil, <i>Cocozelina</i> sp.	5 4 — + 27 28 6.2 8 2 - + 27 24 6.8	4 2 2		
53 <sup>b</sup>	29/12/53	Leaf axil,					
54 <sup>c</sup>	28/1/54	BURKI Leaf axil, <i>Anthonia</i> sp.		3 1 — + .. 7.4	1		TARAWA, GILBERT ISLANDS
55 <sup>c</sup>	28/1/54	BURKI Leaf axil,		8 1 — + ..	1		
56 <sup>c</sup>	28/1/54	BURKI Brickish pond Taro pond		9 3 — + 29 27 7.6 1 2 + - 31 28 8.0	1 1 2 2		TRADARKEE
57 <sup>c</sup>	28/1/54	BURKI					
58 <sup>c</sup>	29/1/54	OLD AIRSTRIP Transient pool		3 3 — + 31 29 7.2	1		FUNAFUTI, ELICE ISLANDS
59 <sup>c</sup>	29/1/54	OLD AIRSTRIP Taro pond		1 3 — + 33 29 7.4	2		
60 <sup>c</sup>	29/1/54	OLD AIRSTRIP Taro pond		1 3 - - 33 29 7.4	2		
61 <sup>c</sup>	29/1/54	OLD AIRSTRIP Salt marsh		10 3 — + 33 29 10.0	1		
62 <sup>c</sup>	29/1/54	VILLAGE Leaf axil		8 1 — + 28 29 6.6	1		
63 <sup>c</sup>	29/1/54	VILLAGE Pierced coconut		7 2 + + 28 29 ..	1		<i>Cocozelina</i> sp.
64 <sup>c</sup>	30/1/54	VILLAGE Pierced coconut		7 2 + + 28 30 5.6	2		shell

63 <sup>a</sup>	30/1/54	VILLAGE	9	3	—	33
		Blackish pond			30	64
66	30/1/54	VILLAGE	3	3	+	7.2
		Transient pool			...	2
67 <sup>b</sup>	1.3./54	GLEN Pool, Strva, 137m	8	2	—	6.8
		Leaf axil.		+	...	1
		<i>Pandanus</i> , sp.		...	...	1
68 <sup>c</sup>	8/3/54	NASDARAVATU, 915m	8	2	+	...
		Leaf axil, wild banana		...	...	1
69 <sup>d</sup>	8/3/54	NASDARAVATU, 975m	8	2	+	20
		Leaf axil, <i>Cordy-</i> <i>line terminata</i> Kunth.		21	64	1
70 <sup>e</sup>	8/3/54	NASDARAVATU, 1055m	8	2	+	20
		Leaf axil.		21	6.6	1
71 <sup>f</sup>	8/3/54	NASDARAVATU, 975m	8	2	+	20
		<i>Preyntelia</i> , sp.		21	6.6	1
72 <sup>g</sup>	8/3/54	NASDARAVATU, 850m	8	2	+	20
		<i>Pandanus</i> , sp.		21	5.8	2
73 <sup>h</sup>	8/3/54	NASDARAVATU, 850m	8	2	+	20
		Leaf axil,		21	5.8	2
74 <sup>i</sup>	9/3/54	NASDARAVATU, 730m	8	2	+	24
		<i>Pandanus</i> , sp.		25	6.4	2
75 <sup>j</sup>	9/3/54	NASDARAVATU, 850m	8	2	+	20
		Leaf axil,		21	6.8	1
76 <sup>k</sup>	9/3/54	Colocasia sp.	8	2	+	24
		NASDARAVATU, 850m		25	6.2	2
		<i>Pandanus</i> , sp.		...	...	1
		NASDARAVATU, 850m	3	3	—	6.0
		Transient forest pool		...	...	2

COLLECTOR	NUMBER	DATE	LOCALITY	HABITAT	CATEGORY	SPECIES	NUMBER OF FOUNDRY FOUNTAIN WATER SOURCES	TEMPERATURE AT TIME OF COLLECTION	PH INDEX	INDEX OF HARDNESS	SHADE	TEMPERATURE AT TIME OF COLLECTION	PH INDEX	INDEX OF HARDNESS	SHADE	TEMPERATURE AT TIME OF COLLECTION	PH INDEX	INDEX OF HARDNESS	SHADE	REMARKS				
77 <sup>a</sup>	9/3/54	NANDARVARU,	350m	Flowing stream	5	3	—	+	28	24	6.4	2	1											
78 <sup>c</sup>	9/3/54	KANDARVARU,	872m	Leaf axial	8	2	—	+	.....	.....	6.4	2	1											
79 <sup>c</sup>	10/3/54	NANDARVARU,	850m	Por hole in rock	6	4	—	+	18	19	6.6	2	1											
30 <sup>c</sup>	10/3/54	NANDARVARU,	850m	Stream flowing over concrete spillway	5	1	—	+	20	19	6.6	2	2	Submerged algal masses throughout										
81 <sup>c</sup>	10/6/54	LAKE PLACID, CAIRES	1	3	—	+	21	20	7.0	2	2													
82 <sup>c</sup>	10/6/54	Edge of lake CAIRES	5	4	—	+	22	21	8.2	2	2													
83 <sup>c</sup>	10/6/54	Flowing stream CAIRES	5	4	—	—	30	21	3.2	3	2	Submerged algal masses throughout												
34 <sup>a</sup>	13/6/54	KURANGA, 300m Ponded stream	4	4	—	+	20	20	7.0	2	2	Submerged algal masses												
85 <sup>c</sup>	15/6/54	Shallow pool Borrow pit	1	3	+	+	25	22	6.2	2	2													

QUEENSLAND, AUSTRALIA

DISTRIBUTION OF AQUATIC FAUNA AND FLORA, WITH  
OBSERVATIONS ON MOSQUITO BIOLOGY

**ALGAE.** Perhaps the most striking feature of the lists presented in Table III is the fact that wherever the material collected was in a fit state for specific determination it proved referable to known species which are cosmopolitan or at all events very widely distributed. The algae identified from the Tokelau Group—*Chroococcus turgidus* and *Lynghya mertensiana*—are, despite the isolation of these atolls, just as likely to be met with in similar aquatic habitats in the North Temperate Zone. The same may be said for the species determined from Funafuti, Ellice Islands. Even an alga recorded from a *Colocasia* leaf axil at 931 metres in the central ranges of Guadalcanal (coll. no. 223) was found to belong to a known species, the cosmopolitan *Ulothrix zonata*. This is a cool-weather alga in North American surface waters, being prevalent in the spring and autumn but disappearing during the summer (Smith, 1930). The temperature of the water in taro leaf axils is more often than not below that of the air (p. 170), and perhaps this was the determining factor in the development of *U. zonata* in so unusual a habitat in the Solomons.

TABLE III  
OCCURRENCE AND DISTRIBUTION OF ALGAE\*

SYSTEMATIC POSITION AND COLLECTION NUMBER	NO. OF TIMES COL- LECTED	LOCALITY									
		Queensland	New Caledonia	Salomon Is.	New Hebrides	Fiji	Tonga	Samoa	Cook Is.	Gilbert Is.	Ellice Is.
<b>CHLOROPHYTA</b>											
Tetrasporales/Palmellaceae											
<i>Gloeocystis empla</i> Kütz. 51 <sup>1</sup>	.	.	1			x					
Ulotrichales/Ulotrichaceae											
<i>Ulothrix zonata</i> (Weber and Mohr.) 223	.	1	x								
Oedogoniales/Oedogoniaceae											
<i>Oedogonium</i> spp. 65, 138, 139, 140, 142, 253, 277, 50 <sup>1</sup>	.	8	x	x	x	x					
<i>Oedogonium intermedium</i> Wittm. 369	.	1	x								
<i>Oedogonium rigidum</i> Illm. 328	.	1	x								
Cladophorales/Cladophoraceae											
<i>Rhizoclonium hieroglyphicum</i> (Agardh) 42, 140, 145, 170, 311, 312	.	6	x			x	x				
<i>Pithophora kewensis</i> Wittrock 21 <sup>1</sup>	.	1					x				
<i>Pithophora toetelii</i> (Roth.) 170	.	1					x				
<i>Pithophora sumatrana</i> (Mart.) 142	.	1		x							
<i>Spongomerpha</i> sp. 21 <sup>1</sup>	.	1		x							
<i>Cladophora fracta</i> (Dillw.) 210, 211	.	2	x								
<i>Rhizoclonium</i> aff. <i>kernerii</i> Steck 267	.	1	x								
Chlorococcales/Scenedesmaceae											
<i>Scenedesmus quadricauda</i> (Turp.) 17	.	1		x							
<i>Scenedesmus dimorphus</i> (Turp.) 96, 277	.	2	x	x							
<i>Scenedesmus bijuga</i> (Turp.) 96, 277	.	2	x	x							
<i>Scenedesmus acutiflorans</i> Schroeder 339	.	1	x								
Chlorococcales/Hydroidictyaceae											
<i>Pediastrum boryanum</i> Meneg. 65	.	1		x							
<i>Pediastrum niticulum</i> var. <i>brevicornis</i> Racib. 250	.	1	x								
<i>Pediastrum tetra</i> (Ehrenberg) 277	.	1	x								
<i>Pediastrum biradiatum</i> Meyen 372	.	1	x								

\* No attempt is made in this Table or the following ones to indicate the occurrence and distribution of organisms other than as derived from my own data. Many of the locality records are new, while many of the gaps probably merely reflect the inadequacy of the collections concerned. Diatom determinations (Dr. Fr. Hasselt) are not yet to hand.

SYSTEMATIC POSITION AND COLLECTION NUMBER	LECTUS	No. OF TIMES	LOCALITY					
			QUEENSLAND	SOLOMON IS.	NEW CALEDONIA	NEW HEBRIDES	FJII	TONGA
			SYNOPSIS	SYNOPSIS	SYNOPSIS	SYNOPSIS	SYNOPSIS	SUMO
<i>Chlorococcals/Ocystaceae</i>								
<i>Tetraedron enorme</i> (Ralfs.) 277	.. ..	1	x					
<i>Zyglenatales/Zyglenataceae</i>								
<i>Spirogyra</i> spp. (veg.) 6, 12, 17, 29, 31, 35, 8, 9, 10, 11, 45, 46, 57, 58, 62, 63, 67, 103, 116, 118, 119, 122, 144, 29, 182, 196, 205, 207, 213, 227, 228, 250, 282, 283, 50, 300, 51 <sup>1</sup> , 52 <sup>1</sup> , 302, 303, 326, 60 <sup>1</sup> , 336, 80 <sup>1</sup> , 83 <sup>1</sup> , 348, 349, 84 <sup>1</sup> , 354, 359, 360, 364, 365, 369	.. ..	51	x x x x x	x x	x x			
<i>Spirogyra neglecta</i> (Lifas.) 176	.. ..	1			x		x	
<i>Mougeotia</i> spp. (veg.) 40, 176, 50 <sup>1</sup> , 300, 51 <sup>1</sup> , 302, 303, 330, 336	.. ..	9	x		x	x		
<i>Zygnema</i> spp. (veg.) 50 <sup>1</sup> , 51 <sup>1</sup>	.. ..	2			x			
<i>Spirogyra submarmorata</i> (Collins) 144	.. ..	1						
<i>Spirogyra pseudoneoplecta</i> Czurda 311	.. ..	1	x					
<i>Spirogyra longata</i> (Vauch.) 339	.. ..	1	x					
<i>Spirogyra intertia</i> Petit 372	.. ..	1	x					
<i>Mougeotia victoriensis</i> West 372	.. ..	1	x					
<i>Zygnema gorakhpurensis</i> Singh 370, 371	.. ..	2	x					
<i>Zyglenatales/Desmidaceae</i>								
<i>Closterium lanceolatum</i> Kütz. 57 <sup>1</sup>	.. ..	1						
<i>Closterium acerosum</i> (Schrank) 182, 310	.. ..	2						
<i>Comarum</i> spp. 299, 300, 85 <sup>1</sup> , 372	.. ..	4	x					
<i>Euastrum</i> spp. 299, 372	.. ..	2	x		x	x		
<i>Closterium jenneri</i> Ralfs. 139	.. ..	1						
<i>Closterium abruption</i> West 85 <sup>1</sup> , 365	.. ..	2	x					
<i>Closterium parvulum</i> Naeg. 328	.. ..	1	x					
<i>Closterium striolatum</i> Ehrenberg 328	.. ..	1	x					
<i>Closterium striolatum</i> var. <i>borgii</i> Kreiger 372	.. ..	1	x					
<i>Closterium ulna</i> Focke 85 <sup>1</sup>	.. ..	1	x					
<i>Comarum askenayi</i> Schne. 372	.. ..	1	x					
<i>Comarum binum</i> Nordst. 328	.. ..	1	x					
<i>Comarum circulare</i> Reinsch. 372	.. ..	1	x					
<i>Comarum cyathopleurum</i> Nordst. 328	.. ..	1	x					
<i>Comarum globosum</i> Bulnh. 372	.. ..	1	x					
<i>Comarum maculatum</i> Turner 372	.. ..	1	x					
<i>Comarum moniliforme</i> (Turp.) 85 <sup>1</sup>	.. ..	1	x					
<i>Comarum pseudonocrum</i> Wille 328	.. ..	1	x					
<i>Comarum quadratum</i> Lund. 372	.. ..	1	x					
<i>Comarum trilobulatum</i> Reinsch. 330	.. ..	1	x					
<i>Desmidium baileyi</i> (Ralfs.) 330	.. ..	1	x					
<i>Desmidium swartzii</i> Agardh. 328	.. ..	1	x					
<i>Euastrum anisatum</i> Ralfs. 328, 372	.. ..	2	x					
<i>Euastrum anisatum</i> var. <i>dideltiforme</i> Duccell. 372	.. ..	1	x					
<i>Euastrum anatum</i> var. 372	.. ..	1	x					
<i>Euastrum divergens</i> var. <i>australianum</i> Borge 372	.. ..	1	x					
<i>Euastrum sinuosum</i> Lenorm. 85 <sup>1</sup> , 372	.. ..	2	x					
<i>Gonatozygon novotocaicum</i> De Bary 372	.. ..	1	x					
<i>Hydrotheca divisa</i> (Smith) 85 <sup>1</sup>	.. ..	1	x					
<i>Micrasterias alata</i> Wallich. 372	.. ..	1	x					
<i>Micrasterias mahabaleshwarensis</i> Illohs. 328	.. ..	1	x					
<i>Micrasterias mohii</i> (Borge) 372	.. ..	1	x					
<i>Micrasterias mohii</i> var. 372	.. ..	1	x					

SYSTEMATIC POSITION AND COLLECTION NUMBER		NO. OF TIMES COL- LECTED	LOCALITY
<i>Micrasterias pinnatifida</i> (Kütz.) 372	..	1	x
<i>Micrasterias torreyi</i> Bailey 372	..	1	x
<i>Pleurolaenium coronulatum</i> Grun. 372	..	1	x
<i>Pleurolaenium ehtenbergi</i> (Breb.) 372	..	1	x
<i>Pleurolaenium eugenicum</i> (Turn.) 330, 372	2	x	
<i>Pleurolaenium karei</i> Rab. 35 <sup>1</sup>	..	1	x
<i>Pleurolaenium oxatum</i> Nordst. 330	..	1	x
<i>Pleurolaenium verrucosum</i> (Bail.) 372	..	1	x
<i>Staurastrum bicorne</i> Hauff. 85 <sup>1</sup>	..	1	x
<i>Staurastrum elevi</i> Roy (?) 85 <sup>1</sup>	..	1	x
<i>Staurastrum curvatum</i> West 85 <sup>1</sup>	..	1	x
<i>Staurastrum furcigerum</i> Bréb. var. 372	..	1	x
<i>Staurastrum leptacanthum</i> Nordst. 372	..	1	x
<i>Staurastrum punctulatum</i> var. <i>kjellmanii</i> Wille 330	..	1	x
<i>Staurastrum pygmaeum</i> Breb. 328	..	1	x
<i>Xanthidium acanthophorum</i> Nordst. 372	..	1	x
<i>Xanthidium antilopaeum</i> var. <i>javanica</i> Nordst. 372	..	1	x
<i>Xanthidium armatum</i> var. <i>cervicornis</i> West 85 <sup>1</sup>	..	1	x
<i>Xanthidium</i> sp. 85 <sup>1</sup> , 372	..	2	x
Charales/Characeae			
<i>Chara zeylanica</i> f. <i>inconspicua</i> (Kütz.) 141	1		x
<i>Nitella microcarpa</i> Br. 84 <sup>1</sup>	..	1	x
<i>Nitella superba</i> Pal. 84 <sup>1</sup>	..	1	x
Undetermined Characeae 343, 360, 364	..	3	x
CHRYSOCOPHYTA			
Heterococcales/Gloeobryotriaceae			
<i>Chlorobryotus regularis</i> Bohlin 57 <sup>1</sup>	..	1	x
Heterosiphonales/Vaucheriacae			
<i>Vaucheria</i> sp. 124, 23 <sup>1</sup>	..	2	x
CYANOPHYTA			
Chroococcales/Chroococcaceae			
<i>Chroococcus turgidus</i> (Kütz.) 55, 64, 138, 139, 143, 113, 27, 182, 250, 277, 57 <sup>1</sup> , 60 <sup>1</sup> , 61 <sup>1</sup>	13	x x	x x x x
<i>Chroococcus minutus</i> (Kütz.) 57 <sup>1</sup>	1		x
<i>Aphanothecia stagnina</i> (Spreng.) 138, 113, 141	3		x
<i>Merismopodium teniusimum</i> Lemm. 138	1		x
<i>Gomphophyllum aponticum</i> Kütz. 143, 145, 250	3	x x	
Oscillatoriophores/Oscillatoriaceae			
<i>Oscillatoria</i> spp. 72, 114, 27 <sup>1</sup> , 253, 308, 320	6	x x	x x
<i>Lynghya wortiensis</i> Menegh. 143, 118, 27 <sup>1</sup>	3	x x	x
<i>Lynghya semipeltata</i> Agardh. 61 <sup>1</sup>	1		x
<i>Oscillatoria princeps</i> Vauch. 138, 115, 146, 170, 59 <sup>1</sup> , 60 <sup>1</sup>	6	x	x x
<i>Lynghya aestuaria</i> Liebm. 61, 63 <sup>1</sup>	2	x	x
<i>Micrcoleus chthonoplastes</i> (Fl. Dan.) 55, 60, 65 <sup>1</sup>	3	x	x
<i>Oscillatoria limetica</i> Lemm. 57 <sup>1</sup>	1		x
<i>Oscillatoria subrosea</i> Schm. 199, 57 <sup>1</sup>	2	x	x
<i>Oscillatoria mongoensis</i> Kütz. 43	1	x	
<i>Lynghya confervoides</i> Agardh 55	1	x	
<i>Lynghya heteromorphus</i> Lemm. 60	1	x	

SYSTEMATIC POSITION AND COLLECTION NUMBER	No. OF TIMES COL- LECTED	LOCALITY									
		QUEENSLAND	SOLOMON IS.	NEW CALEDONIA	NEW HEBRIDES	FJII	TONGA	SAOHA	COOK IS.	GILBERT IS.	FILIPPI IS.
<i>Lynbya major</i> Menegh. 113	1										
<i>Lynbya majuscula</i> 144	1										
<i>Lynbya nordgardi</i> Wille 112	1										
<i>Phormidium</i> sp. 41	1										
<i>Lynbya</i> sp. 145, 285, 331, 334	3	x	x	x							
<i>Oscillatoria jenensis</i> Schmidt 195	1	x									
<i>Oscillatoria subtilissima</i> Kütz. 285	1	x									
<i>Lynbya arruginosa-caerulea</i> (Kütz.) 266, 341	2	x	x								
<i>Oscillatoria amphibia</i> Agardh 339	1	x									
<i>Phormidium inundatum</i> Kütz. 333	1	x									
<i>Spirulina major</i> Kütz. 339	1	x									
<i>Oscillatoriales/Nostocaceae</i>											
<i>Cylindrospermum</i> sp. 64	1									x	
<i>Anabaena</i> spp. 118, 195, 199, 320	4	x		x			x				
<i>Anabaena cylindrica</i> Lemni. 303	1			x							
<i>Anabaena inequalis</i> (Kütz.) 80 <sup>o</sup>	1			x							
<i>Cylindrospermum minutissimum</i> Collins 77 <sup>1</sup>	1			x							
<i>Oscillatoriales/Scytomenataceae</i>											
<i>Pectonema notatum</i> Schm. 303, 65 <sup>1</sup>	2			x							
<i>Pectonema gracillimum</i> (Zopf) 305	1									x	
<i>Tolyphothrix tenuis</i> Kütz. 20 <sup>o</sup> , 115	2						x				
<i>Pectonema</i> sp. 138	1			x							
<i>Tolyphothrix distorta</i> Kütz. 144, 250	2			x							
<i>Tolyphothrix laeta</i> (Desv.) 143	1			x							
<i>Tolyphothrix</i> sp. 65	1			x							
<i>Pectonema horizon</i> Gonont. 266	1	x									
<i>Scytisma bohneri</i> Schm. 328	1	x									
<i>Oscillatoriales/Rivulariaceae</i>											
<i>Calothrix braunii</i> Born. and Flah. 176	1			x							

The extreme paucity of desmids in the insular habitats as compared with the Australian ones is noteworthy. The former yielded only five species from six of the collections, while 15 species were included in five collections from Queensland. This is perhaps not surprising insofar as the atolls are concerned, for it is well known that desmids are calciphobes and rarely feature in the calciphilic flora of limestone regions (Smith, 1950). The three species from atoll ponds (Tarawa, coll. nos. 57<sup>1</sup>, 310; Uvea, coll. no. 139) are all referable to the genus *Clasterium*, several species of which occur in hard waters (Smith, 1950). It is less understandable in regard to such raised islands as Upolu, Viti Levu, Aneitum, New Caledonia and Guadalcanal, for many collections were made in these from soft waters of a reaction within the limits (pH 6.2-8.1) from which desmids were recorded so abundantly in Queensland. It should perhaps be mentioned, in view of the fact that desmids are acidophilic organisms of maximal abundance within the range pH 5.1-5.9 (Wehrle, 1927), that the reaction of pond no. 372 (pH 8.4), from which 29 species and varieties were collected, was strongly influenced by the presence of masses of *Spirogyra luctuana* and *Mougeotia victoriensis*. A marked diurnal fluctuation in the pH value is apparent in ponds in which algal photosynthesis is proceeding actively in the presence of sunlight, the maximal values being attained in periods of maximal oxygen concentration (Nicol, 1935). As coll. no. 372 was made at 11 a.m., and the pond in question had been exposed to bright

sunshine all morning, the oxygen concentration must have reached a high level by then.

Cyanophyta occurred in a high percentage of freshwater- as well as brackish habitats in atolls, most of the species identified being well-known cosmopolitan ones. In high islands and in Australia, however, the flora of freshwater ponds included proportionately fewer blue-green algae. Thus 17 collections of Chlorophyta and 13 of Cyanophyta were made from 20 freshwater habitats in Uvea, Sikaiana, Aitutaki, Tarawa and Funafuti; 58 of Chlorophyta and 18 of Cyanophyta were made from 47 such habitats in New Caledonia, Aencityum, Guadalcanal, Viti Levu and Upolu; while 68 of Chlorophyta but only two of Cyanophyta were made from nine freshwater stations in Queensland. The respective ratios of Chlorophyta to Cyanophyta were thus 1.3:1, 3.1:1 and 34:1. Chapman (1911) has referred to an excess of blue-green algae as being characteristic of tropical ponds, while Smith (1950) pointed out the tendency for Cyanophyta to dominate the algal flora of transient pools (e.g., coll. nos. 114, 195). It would seem that these trends are much more marked in atolls than in high islands and more extensive land masses in the same latitudes.

There is good evidence that winds play an important role in the dispersal of algae, a case in point being the cosmopolitanism of species restricted to special habitats such as hot springs (Smith, 1950). For all that, though, the rarity of obligate freshwater species of Chlorophyta on the atolls, despite the presence of suitable habitats, and the occurrence there of halophilic Cyanophyta and such halophilic Chlorophyta as *Rhizoclonium hieroglyphicum* in both brackish and freshwater ponds, favour the thesis that ocean currents play a not unimportant part in the dispersal of algae to oceanic islands.

**PHANEROGAMIA.** Strictly aquatic phanerogams are of rare occurrence in the islands east of the Fiji Group. All but one of my records from these islands concern only emergent Gramineaceae and Cyperaceae, much of the material being indeterminable due to the absence of fruiting stages and the only two species identified, *Marisus pennatus* and *Paspalum orbiculare*, being widely distributed throughout the tropics. The single exception, a species of *Nymphaea* from Aitutaki (coll. nos. 116, 121, 122), was probably introduced for its ornamental value. I have been unable to locate any records of true aquatics from the islands concerned with the exception of that of (?) *Lemna paucicostata* Hegelmaier from a forest pool on Savai'i, Samoa (Christophersen, 1935).

The introduced pickerel weed, *Pontederia cordata*, and *Nymphaeidae, indica* were noted in Viti Levu, but once again marginal and emergent grasses and sedges were the phanerogams chiefly associated with mosquito larval habitats. Species identified included the sedges *Cyperus haspan* and *Eleocharis geniculata* which have attained a pantropical distribution by natural means (Good, 1933).

Although comparatively few ground pool collections were made in the New Hebrides these were richer in true aquatics, the duckweed *Spirodela oligorrhiza* being found on Aencityum, Espiritu Santo, Aore and Tutuba (where it was locally extremely common in forest ponds) and *Nymphaoides indica*, *Eichhornia crassipes* (which occurs, but was not collected, in Fiji) and a species of *Potamogeton* also being noted.

*N. indica* and *S. oligorrhiza* were recorded from New Caledonia, where the bulrush *Typha angustifolia* is prominent in the flora of coastal marshes, but *Najas*, *Callitricha*, *Potamogeton*, *Hydrocoleis* and *Eichhornia*, all of which are known from this island (Guillaumin, 1948) were never seen. There, as in the Solomons where a species of *Najas* was the only strictly aquatic phanerogam collected, marginal vegetation dominated the scene. Little has been published concerning the aquatic botany of the Solomon Islands, although Lemnaceae are known to be locally abundant in islands where a calcareous crust is (as in Tutuba) the superficial geological structure (Perry, 1950b) and *Myriophyllum* has been recorded (Perry,

TABLE IV  
OCCURRENCE AND DISTRIBUTION OF PHANEROGAMIA  
LOCALITY

SYSTEMATIC POSITION AND COLLECTION NUMBER	NO. OF TIMES COL- LECTED	QUEENSLAND	SOLOMON IS.	NEW CALEDONIA	NEW HEBRIDES	COOK IS.	GILBERT IS.	TOKELAU IS.
Undetermined Gramineaceae 1 <sup>o</sup> , 12, 29, 33, 38, 9 <sup>o</sup> , 39, 48, 61, 112, 20 <sup>o</sup> , 115, 176, 202, 209, 267, 268, 285, 291, 293, 51 <sup>o</sup> , 52 <sup>o</sup> , 312, 59 <sup>o</sup> , 60 <sup>o</sup> , 320, 329, 334, 310, 81 <sup>o</sup> , 331, 332	33	x x x x x x x x x						
<i>Mariscus pennatus</i> Lam. Cyperaceae 41, 70, 57, 118, 121, 122, 57 <sup>o</sup> , 310, 321, 323, 326	11	x x x x x x x x x						
Undetermined Cyperaceae 8 <sup>o</sup> , 9 <sup>o</sup> , 64, 68, 115, 116, 117, 118, 121, 122, 142, 144, 146, 182, 250, 61 <sup>o</sup> , 63 <sup>o</sup> , 330	18	x x x x x x x x x						
<i>Nymphaea</i> spp. Nymphaeace 116, 121, 122, 326, 327, 339	6	x x x x x x						
<i>Fimbristylis</i> sp. Cyperaceae 190	1	x x x x x x						
<i>Oplismenus</i> sp. Gramineace 189	1	x x x x x x						
<i>Paspalum orbiculare</i> Gramineaceae 57, 190, 354, 368	4	x x x x x x						
<i>Fimbristylis militacea</i> (L.) Cyperaceae 6 <sup>o</sup>	1	x x x x x x						
<i>Pontederia cordata</i> L. Pontederiaceae 1 <sup>o</sup>	1	x x x x x x						
<i>Cyperus</i> spp. Cyperaceae 6, 34 <sup>o</sup> , 6 <sup>o</sup> , 10 <sup>o</sup> , 11 <sup>o</sup> , 44, 103, 104, 105, 271	10	x x x x x x x x x						
<i>Nymphaoides indica</i> Kunze Menyanthaceae 1 <sup>o</sup> , 17, 57, 11 <sup>o</sup> , 302	5	x x x x x x						
<i>Scirpus</i> spp. Cyperaceae 6, 9, 17, 34, 10 <sup>o</sup> , 41, 42, 43, 71, 103, 105, 271	12	x x x x x x x x x						
<i>Rhizophora</i> spp. Rhizophoraceae 49 <sup>o</sup> , 60 <sup>o</sup>	2	x x x x x x						
<i>Cyperus haspan</i> L. Cyperaceae 5 <sup>o</sup> , 148, 352, 354, 356	5	x x x x x x						
<i>Blecharis geniculata</i> (L.) Cyperaceae 39, 341	2	x x x x x x						
<i>Juncus</i> sp. Juncaceae 6, 17, 18, 71, 103	5	x x x x x x						
<i>Phragmites communis</i> Gramineaceae 3, 41, 12, 43, 57, 58, 69, 71, 73, 138, 139, 143, 145	13	x x x x x x x x x						
<i>Spirodela oligorrhiza</i> (Kuz) Lemnaceae 6, 9, 3 <sup>o</sup> , 15, 16, 22, 24 <sup>o</sup> , 27, 28, 66, 103, 104	13	x x x x x x x x x						
<i>Typha angustifolia</i> L. Typhaceae 44, 46, 69, 71, 339	5	x x x x x x						
<i>Lichornia crassipes</i> (Mart.) Pontederiaceae 105	1	x x x x x x						
<i>Potamogeton</i> aff. <i>natas</i> L. Potamogetonaceae 104, 105	2	x x x x x x						
<i>Costularia arundinacea</i> Kükenthal 44	1	x x x x x x						
<i>Eriocaulon scariosum</i> Eriocaulaceae 45, 66, 356	3	x x x x x x						
<i>Sesuvium portulacastrum</i> L. Aizooaceae 61, 310	2	x x x x x x						
<i>Enhydria paludosa</i> D. C. Prod. Compositae 266	1	x x x x x x						
<i>Najas</i> sp. Najadaceae 266	1	x x x x x x						
<i>Callitricha</i> sp. Callitrichaceae 361	1	x x x x x x						
<i>Fimbristylis biunifimbriata</i> Cyperaceae 331, 335	2	x x x x x x						
<i>Fuirena ciliaris</i> Cyperaceae 327, 328, 335, 350, 354, 368	6	x x x x x x						
<i>Leersia hexandra</i> Swartz 358	1	x x x x x x						
<i>Lemna minor</i> Lemnaceae 336	1	x x x x x x						
<i>Marsilea</i> sp. Marsileaceae 326, 359, 367	3	x x x x x x						
<i>Myriophyllum</i> sp. Haloragidaceae 356	1	x x x x x x						
<i>Najas tenuifolia</i> Najadaceae 338, 361, 85 <sup>o</sup> , 372	4	x x x x x x						
<i>Nymphaea gigantea</i> Nymphaeace 350, 362, 367	3	x x x x x x						
<i>Paspalum distichum</i> Gramineaceae 333	1	x x x x x x						
<i>Pteris polystachya</i> Cyperaceae 337, 338	2	x x x x x x						
<i>Rhynchospora heterocheta</i> Cyperaceae 333	1	x x x x x x						
<i>Scleria chinensis</i> Cyperaceae 332	1	x x x x x x						

1945). A member of the latter genus was probably present in a ponded stream (coll. no. 277) on Guadalcanal, the preserved sample unfortunately being destroyed in transit.

A feature of the Queensland collections was the comparative abundance of aquatic phanerogams as compared with the Pacific islands, species of the genera *Nymphaea*, *Callitricha*, *Lemna*, *Marsilea*, *Myriophyllum* and *Najas* being identified in addition to numerous sedges, grasses and other marginal and emergent plants.

These results, incomplete as they obviously are from a floristic standpoint, do indicate a diminishing utilization of surface water habitats by aquatic phanerogams from west to east across the South Pacific. This trend is also evident from the lack of references to such plants other than pantropical grasses and sedges in accounts of the flora of oceanic islands such as those of Tonga (Hemsley, 1891), Samoa (Christophersen, 1935; 1938), the Cook Group (Wilder, 1931) and the Ellice Islands (Maiden, 1904). It cannot be ascribed to a lack of suitable habitats except of course in the case of such islands as Bellona and Nukunono which lack freshwater ponds altogether and in that of such atolls as Tarawa where freshwater ponds are apt to become brackish through seepage and evaporation in times of drought, for conditions are quite suitable in the high islands and even in certain atolls. Aitutaki for example.

Darwin (1888) stressed the part played by ducks and wading birds in the transoceanic dispersal of the seeds of aquatic plants, indicating that viable seeds may be carried both in the alimentary tract and in mud dried onto the feet and beak. He pointed out that such birds, if blown across the sea to remote islands, would not be likely to alight on the surface of the sea and on gaining the land would be sure to seek out their natural freshwater haunts. It is of significance in this connection that the most widely distributed wader (the Reef Heron, *Egretta sacra*) and duck (the Australian Grey Duck, *Anas superciliosa*) of the South Pacific behave quite differently to those discussed by Darwin, the former being of primarily coastal habit and feeding in the main on reefs and the latter, while living in freshwater habitats where suitable ones are available, showing no reluctance to settle on salt water and even feeding on outer reefs (Mayr, 1945). The lack of suitable natural transportation for obligate freshwater phanerogams is considered to be an important factor in the paucity of these in oceanic islands of the Pacific. The occurrence of representatives of the Lemnaceae to at least as far eastwards as Samoa (Christophersen, 1935) could perhaps be ascribed to human agency. As Good (1953) has indicated, the peculiar growth form of members of this family "tends to favour casual transport" of whole plants such as is scarcely known elsewhere, and some of the present records (coll. nos. 6,103, 104) were from cultivations of taro (*Colocasia antiquorum* or *C. esculenta*), a staple food plant which was broadcast throughout the South Pacific in pre-European native voyagings. On the other hand, Reef Herons and other such coastal birds could certainly have played a part in the dispersal of the salt-tolerant seeds of species of the Gramineaceae and Cyperaceae which occur at the margins of brackish- and freshwater pools throughout this area.

Much has been written about the relationship of various types of aquatic vegetation to mosquito breeding, a relationship which is largely summed up in the observation by Hess and Hall (1945) that, other factors being equal, the promotion of mosquito development is in direct proportion to the linear extent of the intersection between plants, the air and the water surface. Where only the naked stems of emergent plants intersect the water surface of the more permanent types of ponds there is a scarcity of shelter for mosquito larvae, particularly in relation to the attacks of predators, while at the other end of the scale the intersection line is almost or quite eliminated when the surface is covered by plants of the floating leaf type. Intermediate conditions provide the highest

intersection values and the most favourable combinations of food and shelter for the developmental stages of mosquitoes.

The relationship of plants to mosquito production in the South Pacific is in accord with the above observations. Thus vegetation of the erect naked type, such as the reeds in an *Ancityum*ese swamp (coll. no. 73) illustrated in Fig. 49, proved to be associated with a scarcity of larvae, while permanent ponds having steep banks and a low intersection value, and supporting numerous predators (e.g., coll. no. 1<sup>1</sup>, Fig. 45), were apt to contain no mosquitoes whatsoever. Shallow ponds with small areas of open water and abundant vegetation of the flexuous type such as emergent and marginal grasses and sedges (e.g., coll. no. 103, Fig. 47) frequently exhibited heavy mosquito breeding, as did pools in which a high intersection value was achieved by masses of floatage— for example grass clippings (coll. no. 148), and algae and floating leaves (coll. no. 370, Fig. 53). Three most interesting instances were noted of a maximal intersection value being achieved not by plants but by floating pumice which quite covered the surface of the larval habitats concerned. Narrow water spaces were left between the uneven faces of adjacent lumps of pumice. In two of these stations (coll. nos. 52, 54, Art) *Culex annulirostris* larvae were abundant, while in the other (coll. no. 94, *Ancityum*) the developmental stages of *Anopheles farauti* were extremely abundant in association with a few rare larvae of *C. annulirostris*.

The floating leaf cover of overlapping water lily pads (*Nymphaea* sp.) illustrated in Fig. 44 (coll. no. 122, Aitutaki) provides an example of a very low intersection value resulting from an abundance of floating plants. A very few larvae of *C. annulirostris* were dipped from among these pads, while a reach of the same taro irrigation lacking water lilies and having only marginal grasses providing cover of the flexuous type supported abundant larvae of this mosquito.

A particularly significant correlation between phanerogams and mosquito breeding was noted on the small island of Tutuba in the northern New Hebrides. This island is about five kilometres long and 1.5 km broad. A pervious layer of coral underlies the thin soil of the flat northern half, which is only a little above sea level and carries a coconut plantation. The southern end of the island rises to about 30 metres above sea level. It is quite heavily bushed, and the indigenous Melanesian inhabitants have their villages there. Wartime United States malaria control officers noticed the absence of anophelines from Tutuba, a fact of decided interest in view of the abundance of *An. farauti* on the coastal strip of southeastern Espiritu Santo, three kilometres across Seoril Passage from the northern end of the island, and on Aore, about the same distance from the southwestern end. My first visit to Tutuba was in early 1945 with members of an American Naval malaria control unit, and on that occasion a day's collecting yielded no anophelines whatsoever although *C. annulirostris* proved to be abundant.

Several days were spent on Tutuba in August, 1952, and a thorough larval survey was undertaken. No permanent larval habitats were located in the coconut plantation, where rainwater quickly soaks away into the underlying coral, but one of the villagers guided the way to a series of extensive ponds of up to 30 metres in diameter. These were in forest clearings and occupied depressions in the summit plateau. Their permanency was attested to not only by their biology but by the fact that each had its own native name and its associations with local folklore. The most striking thing about these ponds was the thick plusion of duckweed (*Spirodela oligorrhiza*) which in all cases completely covered the surface giving them the appearance on casual examination of tufty forest glades (Fig. 43, coll. no. 3<sup>1</sup>).

Of the eight ponds studied at length two proved to be altogether lacking in mosquitoes. In five, larvae of *Culex fraudatrix* were present although rare, a few *Culex fusciferus* also being associated with the first-named species in one of these, while *C. fraudatrix* was abundant in pig wallowings where *Spirodela* was only present in small rafts at the edges of the remaining pond. The edges of most of the ponds

showed evidence of fouling by pigs, but in all but the one just mentioned the duckweed pleuston was unbroken. The water was clear although of a rather leaden tint in five of them, and was slightly turbid in the remaining three; its reaction was usually rather acid, the hydrogen ion content ranging from pH 6.6 (in four pools) to pH 7.0. Algae other than diatoms were not recorded from any of the ponds, but Protozoa were plentiful although of few species and the colonial rotifer *Conochilus hippocrepis* was abundant in one instance. The macrofauna included several species of Odonata, Hemiptera and Coleoptera.

Rao (1933) studied a *Lemna*-covered pond in England, drawing attention to the poorness of its aeration because of the protection from wind action afforded by the blanketing duckweed and stating that the low concentration of oxygen combined with a high concentration of albuminoid ammonia rendered the water unsuitable for green algae although the conditions encouraged the growth of diatoms and Mastigophora. He noticed a strong smell of hydrogen sulphide on disturbing the water sheet, and this was also the case in Tutuba. The absence of Chlorophyta from Solomon Island and New Hebridean ponds having a duckweed pleuston was commented on by Perry (1950b), who was of the opinion that a reduction in food potential was one of the factors bound up with the absence of anophelines from such ponds. However, the alimentary tract of culicine larvae from the Tutuba pools proved to contain large numbers of diatoms and flagellates, especially *Phacus*, which normally figure in the gut contents of *An. farauti*.

A quantity of *Spirodela* was taken from Tutuba to the laboratory on Espiritu Santo, where varying amounts of it were added to glass pans containing larval *An. farauti* and *C. annulirostris* in water from a natural habitat. Both species thrived so long as patches of unobstructed water remained between scattered rafts of duckweed. However, when the *Spirodela* was allowed to cover the water surface completely, *An. farauti* larvae quickly died, although in the presence of abundant food, through their inability to obtain air at the water surface. Many of the culicines, on the other hand, survived, being able to push the tip of the siphon into such tiny interspaces as still remained here and there among the overlapping plants.

*An. farauti* was collected in nature in ponds containing scattered rafts of *S. oligorrhiza* on Aincityum (coll. nos. 6, 103, 104) and Aore (coll. no. 9), the larvae actually being dipped in their greatest numbers from the shelter of these rafts. It thus seems that so long as the *Spirodela* serves to increase the intersection value anopheline breeding is not only unimpeded but is positively favoured, while the virtual elimination of the intersection line consequent on the development of uninterrupted carpets of duckweed, as on Tutuba, raises an insuperable mechanical barrier to anopheline larval development although it still permits a certain amount of culicine breeding. The excessive rarity of culicine larvae under these conditions is probably bound up at least in part with their difficulty in escaping from the attacks of predators. The water bugs *Enithares* sp. and *Plea rufonotata* were abundant in the Tutuba ponds, and Johnson (1903) pointed out that duckweed-covered waters in America are apt to harbour predaceous water bugs in great numbers. These conclusions are in agreement with those of other workers, for Adie (1904) found that *Lemna*-covered tanks in India do not harbour mosquito larvae but that if areas are cleared of the weed and kept so by floating structures anophelines will oviposit in these open places and their larvae will develop there. Bentley (1910) reported that if the continuity of the blanket of another duckweed (*Wolffia*) in India is broken by emergent vegetation, mosquito larvae can exist without difficulty, while it has recently been stated (Anon., 1947) that high production of *Anopheles quadrimaculatus* occurs in America when duckweeds only partially cover the water surface.

It seems likely, however, that the local conditions which favour a high production of *Spirodela* in the only permanent surface waters on Tutuba operate against the establishment of *An. farauti* there. Although the effective flight range

of this mosquito is normally limited to about one mile (1.6km) (Daggy, 1945) it is most unlikely that sporadic introductions do not take place from time to time across the three kilometres separating the island from Aore and Espiritu Santo. If such introductions were to take place at the height of the rainy season *An. farauti* could perhaps establish itself for brief periods, breeding in transient rain pools on the low-lying northern end of the island, but the complete lack of any dry season larval habitats beyond *Spirodela*-covered pools in the forests would weigh heavily indeed against any permanent establishment.

Half a century ago Johnson (1903) urged in America that ponds wholly covered by duckweed should never be treated with larvicultural oil "for nature has provided a far more lasting and equally effective protection," while in India Adie (1904) suggested the deliberate promotion of the growth of *Lemna minor* in all unavoidable collections of water as a mosquito control measure. Another duckweed of the genus *Azolla* was actually used in this manner in the former German colonies in Africa, but the initial enthusiasm for the project was dampened when it proved under field conditions that the plants would not grow in dense or even moderate shade and were thus useless in the very forest pools where they were most needed (Howard et al., 1912).

From the experience of the German workers in Africa it would seem that *Spirodela oligorrhiza*, which flourishes under forest conditions in the New Hebrides, might have been of more use to them than *Azolla*. It is not considered that the former plant could be employed to help check anopheline breeding in the malarious islands of the South Pacific at large, for shallow semi-permanent ponds and transient pools, among the most important larval habitats of the dangerous anophelines of the region, are unsuited to the development of abundant populations of Lemnaceae (Howard et al., 1912). *Spirodela* is, nevertheless, of decided value as a check on anopheline breeding wherever, as on Tumbua, local conditions so favour development that the intersection line is eliminated.

**PROTOZOA.** Only one group was fully investigated, those ciliates of the order Peritrichia which live as ectocommensals on mosquito larvae (p. 101, ff.). A low power field microscope was employed in recording the presence or absence of free living protozoans in 10cc centrifuged samples of water from many habitats, but relatively few identifications were made. The time available in the field seldom allowed of the detailed examination of living specimens which is particularly necessary for the accurate determination of small forms which do not lend themselves to preservation, such as the smaller and more delicate ciliates and minute flagellates. Such specific determinations as were made (Table V) fully support the views of Schewiakoff (1893) and Edmondson (1910) on the cosmopolitanism of these animals. While some of the protozoans observed at length could only be identified generically from the literature at hand, the majority corresponded very well with the descriptions of known species published by Kahl (1930-35), Kudo (1946) and other authors.

Widespread euglenid flagellates are frequently conspicuous amongst the gut contents of mosquito larvae (p. 138, ff.), remaining recognizable even in alcohol-and formalin-preserved samples because of the resistant nature of the pellicle. The species of *Phacus* illustrated in Fig. 32 (and in a partly digested state in Figs. 35-37) was recorded from both surface water and containers from Queensland to Funafuti. It ranges from 35 $\mu$  to 70 $\mu$  in length and from 23 $\mu$  to 50 $\mu$  in breadth (av. 50 $\mu$  by 35 $\mu$ ) and has a flagellum as long as, or rather longer than, the body. There is a prominent dorsal fold anteriorly and the pellicle is longitudinally striated. A conspicuous paramylon body is usually apparent amongst the mass of discoidal green chromatophores. This species is herein referred to *Phacus pleuronectes* (Müller) from the descriptions of Walton ((1915) and Kudo (1946). Other species of the genus encountered included *P. curvicauda* Swir., *P. caudatus* Hübner and *P. longicaudus* (Ehrenberg) (Fig. 33). Several collections preserved

TABLE V  
OCCURRENCE AND DISTRIBUTION OF FREE-LIVING PROTOZOA  
LOCALITY

SYSTEMATIC POSITION AND COLLECTION NUMBER	LECTED	NO. OF TIMES COLLECTED	QUEENSLAND	SOLOMON IS.	NEW CALEDONIA	NEW HEBRIDES	FJJI	TONGA	SAMOA	COOK IS.	GILBERT IS.	ELICE IS.	TOKELAU IS.
<b>MASTIGOPHORA</b>													
<i>Bodo caudatus</i> (Dujardin) Protonomonadina/ Bodonidae 3 <sup>1</sup> , 4 <sup>1</sup> , 22, 24, 27, 12 <sup>1</sup> , 47, 99, 28 <sup>1</sup> , 171, 269, 301, 62 <sup>1</sup> , 71 <sup>1</sup> , 319, 74 <sup>1</sup>		16	x x x x x	x				x	x x				
<i>Phacus</i> spp. Euglenoidina/Euglenidae 1 <sup>1</sup> , 31, 12 <sup>1</sup> , 158, 272, 292, 322, 343, 351, 362		10	x x x x x x							x			
<i>Phacus pleurorectes</i> (Müller) Euglenoidina/ Euglenidae 1 <sup>1</sup> , 3 <sup>1</sup> , 17, 30, 66, 117, 121, 170, 172, 29 <sup>1</sup> , 250, 265, 274, 292, 302, 57 <sup>1</sup> , 312, 316, 325, 372		20	x x x x x x x x x x x x x x x x										
<i>Trachelomonas hispida</i> (Perty) Euglenoidina/ Euglenidae 1 <sup>1</sup> , 3 <sup>1</sup> , 30, 12 <sup>1</sup> , 172, 57 <sup>1</sup> , 265, 274, 292, 312, 316, 325		12	x x x x x x x x x x x x x x x x										
<i>Phacus curvicauda</i> Swir. Euglenoidina/ Euglenidae 182, 310		2					x	x					
<i>Pandorina mucum</i> (Müller) Phytomonadina/ Volvocidae 7, 39, 45, 308, 330, 355, 364		7	x x x	x x					x				
<i>Trachelomonas armata</i> (Ehrenberg) Euglenoidina/Euglenidae 48, 176, 273		3	x x x				x						
<i>Astasia</i> sp. Euglenoidina/Astasiidae 73 <sup>1</sup>		1		x									
<i>Chlamydomonas monadina</i> Stein Phytomonadina/Chlamydomonadidae 321		1		x									
<i>Cruenula ova</i> (Ehrenberg) Euglenoidina/Euglenidae 302		1		x									
<i>Menidium incurvum</i> (Fresenius) Euglenoidina/ Astasiidae 70 <sup>1</sup>		1		x									
<i>Monas</i> sp. Protonomonadina/Monadidae 316, 317, 67 <sup>1</sup>		3		x									
<i>Pleuronema</i> sp. Protonomonadina/Bodonidae 67 <sup>1</sup>		1		x									
<i>Volvox</i> sp. Phytomonadina/Volvocidae 302		1		x									
<i>Oikomonas terro</i> (Ehrenberg) Protonomonadina/ Oikomonadidae 103, 301		2		x x									
<i>Chilomonas paramaecium</i> Ehrenberg Cryptomonadina/Cryptomonadidae 12 <sup>1</sup> , 99, 316, 317, 69 <sup>1</sup> , 321, 75 <sup>1</sup>		7		x x x									
<i>Phacus longicaudus</i> (Ehrenberg) Euglenoidina/ Euglenidae 259, 302		2	x		x								
<i>Euglena</i> spp. Euglenoidina/Euglenidae 274, 276, 302, 325, 351		5	x x		x								
<i>Phacus caudatus</i> Hübner Euglenoidina/Euglenidae 339		1	x										
<b>SARCOPODA</b>													
<i>Actinophrys sol</i> Ehrenberg Actinopoda/Actinophidae 301		1		x									
<i>Amoeba radiosa</i> Ehrenberg Amoeboidea/ Amoebidae 1 <sup>1</sup>		1		x									
<i>Choan</i> diffusen. L. Amoeboina/Amoebiidae 302		1		x									
<i>Undatellina</i> sp. Heliozoa 1 <sup>1</sup> , 74 <sup>1</sup>		2		x									
<i>Arella</i> sp. Testacea/Archelidae 3 <sup>1</sup> , 66, 239, 285, 302, 336, 85 <sup>1</sup> , 364		8	x x x x x x										
<i>Difflugia</i> spp. Testacea/Difflugidiidae 104, 220, 250, 322		1	x	x									
<b>CHILOPODA</b>													
<i>Coleps hirtus</i> (Müller) Holotrichia/Colepidae 23, 72, 156		3		x						x			
<i>Coleps elongatus</i> Ehrenberg Holotrichia/Colepidae 1 <sup>1</sup>		1		x						x			

SYSTEMATIC POSITION AND COLLECTION NUMBER	No. OF TIMES COL- LECTED	LOCALITY										
		Queensland	Solomon Is.	New Caledonia	New Hebrides	Fiji	Tonga	Samoan	Cook Is.	Gilbert Is.	Ellice Is.	Tolemais Is.
<i>Colpidium colpoda</i> (Ehrenberg) Holotricha/ Frontoniidae 325	1				x							
<i>Colpoda</i> sp. Holotricha/Colpodidae 50 <sup>1</sup>	1				x							
<i>Cyclidium</i> sp. Holotricha/Pleuronematidae 67 <sup>1</sup> , 68 <sup>1</sup>	2				x							
<i>Didinium navelatum</i> (Müller) Holotricha/Didini- idae 302	1				x							
<i>Dileptus anser</i> (Müller) Holotricha/Tracheli- idae 302	1				x							
<i>Loxodes magnus</i> Stokes Holotricha/Loxodidae 302	1				x							
<i>Paramecium caudatum</i> Ehrenberg Holotricha/ Paramecidiidae 301, 73 <sup>1</sup>	2				x							
<i>Paramecium putrinum</i> Claparède and Lachmann Holotricha/Paramecidiidae 302	1				x							
<i>Spirostomum ambiguum</i> Ehrenberg Spirotricha/ Spirostomidae 48 <sup>1</sup>	1				x							
<i>Tetrahymena</i> sp. Holotricha/Frontoniidae 302	1				x							
<i>Pleuronema</i> spp. Holotricha/Pleuronematidae 17, 301	2				x	x						
<i>Steinor</i> spp. Spirotricha/Stentoridae 1 <sup>1</sup> , 66	1		x	x								
<i>Halteria granindella</i> (Müller) Spirotricha/ Hal- teriidae 3 <sup>1</sup> , 17, 274, 322	4	x	x	x								
<i>Homalognatha</i> sp. Holotricha/Frontoniidae 3 <sup>1</sup>	1			x								
<i>Paramecium</i> spp. Holotricha/Paramecidiidae 72, 99, 269	3	x	x	x								
<i>Coleps</i> spp. Holotricha/Colepidae 17, 66, 363	3	x	x	x								

in formalin were only identified generically (Table V) but it is considered that the majority of these—one of which was made from a coconut palm reservoir at Nukunono— are probably referable to *P. pleuronectes*.

Another euglenid flagellate, referable to the genus *Trachelomonas* and identified from the data of Walton (1915) and Kudo (1916) as *T. hispida* (Perty) was usually associated with *P. pleuronectes* and was also recorded from Queensland to Funafuti. *T. hispida* (Fig. 34) has a minutely spined lorica of a brownish colour measuring from  $20\mu$  to  $10\mu$  by  $15\mu$  to  $28\mu$ , most of the examples seen being towards the lower end of the size range. The free flagellum is from  $1\frac{1}{2}$  to  $2\frac{1}{2}$  times as long as the body. There are about 10 chromatophores, and the posteriorly located vesicular nucleus shows up clearly by phase contrast illumination. Another species of the genus, *T. armata* (Ehrenberg), was recorded from Upolu, Guadalcanal and Ait (where numerous examples were recovered from chironomid pupal pelts, *Tendipes* sp.).

The habitats from which euglenids were recorded included simple containers and various types of surface water. There was frequently evidence of pollution by animals, and both *Phacus* and *Trachelomonas* were particularly abundant under such conditions (e.g., coll. nos. 30, 271) although they were never responsible for green or yellowish brown water blooms which may occur in such cases according to Tiffany (1951). The frequency of association and the ubiquity of *P. pleuronectes* and *T. hispida* are noteworthy, for during an investigation in England Howland (1930) found the former species in eight ponds in all but one of which *T. hispida* was present as well.

**PORIFERA.** Freshwater sponges are not known from any of the Pacific islands east of Fiji. Adamson (1935) considered it probable that this group has failed to reach any of the oceanic islands of the region. The Fijian species, *Spongilla gilsoni* Topsent, was collected twice in Viti Levu. It was found as an encrustation on the underside of floating logs and sticks in a still backwater (coll. no. 50<sup>1</sup>) and an oxbow pond (coll. no. 51<sup>1</sup>). While sponge gemmules are perhaps liable to a degree of wind dispersal, there is little doubt but that the Porifera reached their present limits in Fiji while land connections with western Melanesia still existed.

**COELENTERATA.** Although Northern Hemisphere species of *Hydra* have tended to become widespread, presumably in the course of transportation of useful and ornamental aquatic plants, the genus is not known to have become established in any of the oceanic islands of the tropical Pacific with the exception of Oahu, Hawaii (Adamson, 1935). Three species have reached New Zealand, where they are still found only in the immediate vicinity of the larger cities (Powell, 1947), while others are common in parts of Australia.

*Hydra* was never noticed during this investigation except in Queensland. While its occurrence, particularly in the more developed of the high islands, might possibly have been overlooked—for lack of time prevented the employment of special searching techniques—it was certainly quite obvious in Australia on casual field observation. *H. vulgaris* was collected there on three occasions in association with *Lemna minor* and *Nymphaea gigantea* (coll. nos. 336, 362, 367). This brown *Hydra* and other species of the genus have been observed to devour mosquito larvae and even pupae, relevant papers being referred to by Hinman (1934). Ifamlyn-Harris (1932<sup>2</sup>) claimed that a species common in Brisbane waters takes "an enormous toll" of larval life.

The introduction of *H. vulgaris* into suitable Pacific waters, particularly in the New Hebrides and Solomons, would be a simple enough matter. This species is already established in comparable latitudes in Queensland, and while its introduction into the tropical Pacific could cause no harm whatsoever a certain amount of benefit might be expected from the addition of a further biological control agent to those already operating there.

**PLATYHELMINTHES.** Adamson (1935), who spent some time searching for freshwater planarians in the Marquesas with an entire lack of success, was unable to locate any records of the presence of these animals in the tropical Pacific with the exception of Hawaii.

During this project some small and undetermined turbellarians were noted in a taro pond on Aneityum (coll. no. 104), while the cosmopolitan *Mesostoma ehrenbergi* (Focke), presumably a recent introduction, was found in a pond (coll. no. 302) on Viti Levu. Turbellarians, which were poorly preserved and unable to be identified, also figured in a collection from a ponded stream (coll. no. 360) in Queensland. It is considered quite possible that thus-far unnoticed species may occur in the rivers of the larger islands of the western Pacific, for little collecting was done in the faster-flowing clean streams unsuitable as mosquito larval habitats.

**NEMATODA** and **NEMATHELMINTHES.** Free-living nematodes were seldom noticed, and no attempt was made to identify those seen. Small species were observed among the submerged stems of sedges in a pond on Viti Levu (coll. no. 10<sup>1</sup>) and among marginal grasses in Queensland (coll. no. 81<sup>1</sup>).

Undetermined hairworms (Gordioidea) were recorded from a concrete drinking trough at Tutuba (coll. no. 29) and from a Fijian pond (coll. no. 302). A single large example referable to the genus *Chordodes* was found in a ponded stream in Queensland (coll. no. 349).

**ROTATORIA.** Rotifers were collected quite widely from Queensland to Tarawa (Table VI<sup>1</sup>). Wherever the condition of the material permitted they were all found to be referable to known species with the exception of *Lecane* sp. from a

brackish pond on Tarawa (coll. no. 56<sup>1</sup>) which Mr. C. R. Russell, who undertook these determinations, thinks may be undescribed.

TABLE VI  
OCCURRENCE AND DISTRIBUTION OF ROTATORIA  
LOCALITY

SYSTEMATIC POSITION AND COLLECTION NUMBER	NO. OF TIMES COL- LECTED	QUEENSLAND	LOCALITY								
			SOLONON IS.	NEW CALEDONIA	NEW HEBRIDES	Fiji	Tonga	SAMOA	COOK IS.	GILBERT IS.	ELICE IS.
<i>Lecane crepida</i> Harring Euchlanidae 56 <sup>1</sup> . . . . .	1										
<i>Lecane</i> sp. Euchlanidae 56 <sup>1</sup> . . . . .	1								x	x	
<i>Mytilina trigona</i> (Gosse) 56 <sup>1</sup> . . . . .	1								x	x	
<i>Monostyla punctata</i> Murray Euchlanidae 3 <sup>1</sup> , 56 <sup>1</sup> . . . . .	2				x			x		x	
<i>Brachionus quadridentatus</i> Hermann Brachionidae 30, 292 . . . . .	2			x	x						
Indeterminable Bdelloida 267, 293, 303, 67 <sup>1</sup> , 319, 72 <sup>1</sup> , 78 <sup>1</sup> , 80 <sup>1</sup> . . . . .	8		x	x	x	x					
<i>Conochilus hippocrepis</i> (Schrank) Conochiliidae 1 <sup>1</sup> . . . . .	1			x							
<i>Habrotrocha tridens</i> Milne Bdelloida/Philodinidae 325 . . . . .							x				
<i>Lecane luna</i> (Müller) Euchlanidae 303 . . . . .	1						x				
<i>Lecane papuana</i> (Murray) Euchlanidae 303 . . . . .	1						x				
<i>Limnias</i> sp. Flosculariidae 78 <sup>1</sup> . . . . .	1						x				
<i>Monotyla lunaris</i> (Ehrenberg) Euchlanidae 48 <sup>1</sup> . . . . .	1						x				
<i>Polyarthra remata</i> Skorikov, Polyarthridae 303 . . . . .	1						x				
<i>Sinantheria</i> aff. <i>ariprepes</i> Edmondson 302 . . . . .	1						x				
<i>Habrotrocha</i> spp. Bdelloida/Philodinidae 30, 74 <sup>1</sup> . . . . .	2			x	x						
<i>Brachionus dimidiatus</i> (Bryce) Brachionidae 30 . . . . .	1				x						
<i>Brachionus rubens</i> Ehrenberg Brachionidae 30 . . . . .	1				x						
<i>Conochilus unicornis</i> Roussel Conochiliidae 3 <sup>1</sup> . . . . .	1				x						
<i>Monostyla</i> sp. Euchlanidae 6 . . . . .	1				x						
<i>Mytilina centralis</i> (Ehrenberg) 3 <sup>2</sup> . . . . .	1			x							
<i>Lecane formosa</i> Harring and Myers Euchlanidae 267 . . . . .	1			x							
<i>Habrotrocha appendiculata</i> Murray Bdelloida/ Philodinidae 370, 372 . . . . .	2	x									
<i>Monommaea longisteta</i> (Müller) 370 . . . . .	1	x									
<i>Monostyla bulla</i> Gosse Euchlanidae 372 . . . . .	1	x									
<i>Monostyla stenroosi</i> Meissner Euchlanidae 339 . . . . .	1	x									
<i>Proales gigantea</i> (Glascott) Notommatidae 369 . . . . .	1	x									

The cosmopolitanism of rotifers is well known. Their resting stages or winter winter eggs are minute and highly resistant to mechanical damage, and lend themselves to adventitious transportation by winds and in the alimentary tract of birds and other animals (Russell, 1949). Thus lakes in Java and Sumatra have been shown to support the same rotifers found in those of Europe (Rutner, quoted by Welch, 1935), while Murray (1911) recorded 24 widely distributed species from Hawaii, 15 from Fiji and two from Samoa and from the Galapagos but noted only a single species (from Hawaii) that appeared to be new. Twelve mostly cosmopolitan species were collected from surface waters at Yap, Caroline Islands, by Hadya (1940).

My records have a strong bias in favour of Fiji and the New Hebrides where circumstances permitted a more intensive search for these animals than in other places. In any case, as Russell (1949) has pointed out, rotifer populations are liable to rapid and radical change under physical and seasonal influences, and single collections give a very incomplete picture of local faunas. Nevertheless, such sampling as was done provides further evidence of the cosmopolitanism of the phylum. The records are also of interest insofar as rotifers are sometimes

eaten by larval mosquitoes—Meuz (1919) on one occasion noticed larvae of the North American *Anopheles quadrimaculatus* Say or *An. crucians* Wied. feeding almost exclusively upon rotifers, and the remains of these animals were sometimes recognizable in the larval gut contents of *An. farauti* in the New Hebrides, Solomon Is. and Queensland and of *C. annulirostris* in these localities and in Fiji.

**POLYOA.** No representatives of this phylum were collected. The only species known from the South Pacific occur in Lake Vaihiria, Tahiti, where Hastings (1929) discovered an indigenous *Hyalina* and collected the cosmopolitan *Plumatella emarginata* Allman which was also found there by Adamson (1935). Some other freshwater polyoza also have a remarkably wide distribution, which was ascribed by Hamer (1901) to the fact that the statoblast is able to withstand long periods of desiccation without losing its viability. These animals are easily overlooked unless specially searched for, and they exhibit a preference for relatively deep ponds, lakes and quiet streams. Comparatively few of the larval habitats discussed herein fell within these categories.

**ANNELIDA.** Mumford (1936) mentioned the discovery of an oligochaete in Lake Vaihiria, Tahiti, as the first record of an aquatic species from tropical Polynesia. Three genera were represented in my collections, *Audiphorus* (coll. nos. 115, 116, 118, 172, 311, 312); *Nais* (coll. no. 78<sup>1</sup>) and *Dichogaster* (coll. nos. 300, 360). The species of these widely distributed genera are of small size, their cocoons being easily transported in mud by birds and other agents (Stephenson, 1930). Five of the collections were made on atolls, nos. 311 and 312 at Finafuti and nos. 115, 116 and 118 at Aitutaki. In two instances (coll. nos. 312, 118) the worms were dipped from amongst the submerged stems of *Colocasia*, and it is suggested that the initial introductions could easily have been made by way of mud clinging to taro root carried by native voyagers. It is even possible that the adults themselves could survive for a considerable time within the moist leaf bases of taro plants in transit, their hooked chaetae helping to secure them in the deepest recesses.

No leeches were ever found, and it seems likely that freshwater Hirudinea are absent from the tropical South Pacific, although they are known from Hawaii (Mumford, 1936). Freshwater polychaetes were likewise not recorded, although according to the latter author a species has been described from Mangaoreva and another is known from Hawaii; while Baker (1929) recorded *Lycaenias quadraticeps* Gay (previously known only from South America, where it lives in the sea or in fresh water easily accessible from the sea) from Steaming Hill Lake, Gaua, New Hebrides.

**ENIOMOSTRACA.** Fairy shrimps ('Phylopoda') were conspicuous merely by their absence, the only one collected belonging to an undescribed species of the genus *Lynceus* (coll. no. 9, Aore). Cladocera, Copepoda and Ostracoda were frequently abundant. Many of the specimens proved to be referable to known species (Table VII), cosmopolitanism being scarcely less marked than in the Rotatoria, Protozoa and Algae. Smith (1909) indicated that Entomostraca, particularly those found in the smaller bodies of water, have resting eggs which can withstand long periods of desiccation during transportation. Among the Cladocera, for example, the species collected in Queensland are all common in the temperate parts of the Northern Hemisphere, Birge (1915) referring to *Chydorus sphaericus* as occurring in North America and being the commonest of all Cladocera and found all over the world. The harpacticid *Phyllognathus viguerii*, recorded from leaf axils in Viti Levu, is known from similar habitats in Europe, Africa, North and South America and Indonesia (Lang, 1918) : and *Mesocyclops levicarri*, found in transient and permanent pools in Sikaiana, Tutuba and Viti Levu, was stated by Sars (1918) to be one of the commonest cyclopids in ditches, small ponds and lakes in Norway. As regards the ostracods, *Cyprinotus cingalensis*, *Stenocypris malcolmsoni* and *Cypraea globulus* are all widespread in the Indo-Australasian area, while *Heterocypris anomala*, collected at Aore, New Hebrides, was previously known from

TABLE VII  
OCCURRENCE AND DISTRIBUTION OF ENTOMOSTRACA  
LOCALITY

SYSTEMATIC POSITION AND COLLECTION NUMBER	NO. OF TIMES COL. LICED	LOCALITY						
		Queensland	Solomon Is.	New Caledonia	New Hebrides	Fiji	Tonga	Samoa
<b>PHYLLOPODA</b>								
<i>Lyneus</i> sp. 9	1	x						
<b>CLADOCERA</b>								
Undetermined Cladocera	29, 115, 116, 22 <sup>1</sup> , 23 <sup>1</sup> , 27 <sup>1</sup> , 136, 289, 48 <sup>1</sup> , 50 <sup>1</sup> , 302, 360	12	x x x x x			x	x	
<i>Moina</i> sp. Daphnididae 30, 172	2		x		x			
<i>Chydorus?</i> <i>sphaericus</i> (Müller) Chydoridae 333	1	x						
<i>Diaphanosoma?</i> <i>unguiculatum</i> Guiney Sidiidae 333	1	x						
<i>Simocephalus serrulatus</i> (Koch) Daphnididae 338	1	x						
<i>Simocephalus setiferus</i> (Müller) Daphnididae 361	1	x						
<i>Simocephalus setiferoides</i> Daphnididae 371	1	x						
<b>COPROPODA</b>								
Undetermined Cyclopidae 17, 156, 50 <sup>1</sup> , 308, 360	5	x	x x x				x	
<i>Thermocyclops opercularis</i> (Kiefer) Cyclopidae 306	1						x	
<i>Bryocyclops</i> sp. Cyclopidae 293, 316, 69 <sup>1</sup> , 74 <sup>1</sup>	4		x x					
<i>Elaphoidella</i> sp. Harpacticidae 73 <sup>1</sup> , 74 <sup>1</sup> , 78 <sup>1</sup>	3		x					
<i>Cryptocyclops bicolor linjanicus</i> (Kiefer) Cyclopidae 49 <sup>1</sup> , 302	2		x					
<i>Phyllognathopius cignieri</i> (Maupas) Harpacticidae 69 <sup>1</sup> , 74 <sup>1</sup> , 78 <sup>1</sup>	3		x					
<i>Mesocyclops leuckarti</i> (Claus) Cyclopidae 3 <sup>1</sup> , 289, 46 <sup>1</sup> , 302	4	x	x x					
<i>Elaphoidella grandidieri</i> (Guerne and Richard) Harpacticidae 3 <sup>1</sup>	1	x						
<b>OSTRACODA</b>								
<i>Cypridopsis</i> spp. Cyprididae 19 <sup>1</sup> , 158	2		x				x	
<i>Cyprætta globulus</i> (Sars) Cyprididae 115, 170, 285, 49 <sup>1</sup> , 50 <sup>1</sup> , 320, 358	7	x x	x x x x		x			
<i>Stenocypris malcolmani</i> (Brady) Cyprididae 30, 116, 121, 172, 292, 302, 349	7	x	x x x x x					
<i>Darwinula</i> sp. Darwinulidae 75	1		x					
<i>Strandesia rouxi</i> Mées Cyprididae 103, 301	2		x x					
<i>Heterocypris anomala</i> Klia Cyprididae 10	1		x					
<i>Heterocypris</i> spp. Cyprididae 30, 85, 86	3		x					
<i>Globocypris?</i> sp. Cyprididae 9, 327	2	x	x					
<i>Notodromas major</i> Mées Cyprididae 138, 146	2		x					
<i>Cyprinotus cingalensis</i> Brady Cyprididae 142	1	x						
<i>Aeocypris</i> sp. Cyprididae 361	1	x						

Formosa. *Strandesia rouxi*, which was recorded from the New Hebrides and Fiji, was described from New Caledonia, while *Notodromas major* is only known from the New Caledonian area (Harding, p.c. 1955). A few new species were collected, particularly among the Ostracoda (Table VII). Ostracods were sometimes very abundant in terms of numbers of individuals, and Hadya (1940) noted that these animals seem to comprise a rather important part of the freshwater fauna of the isolated island of Yap, Caroline Group.

Wilson (quoted by Hinman, 1934) reported that the cladoceran *Daphnia pulex* (de Geer) will attack mosquito larvae, but as Hinman himself pointed out few of the Entomostraca are large enough to be of significance as predators of the Culicidae. Hintz (1951) demonstrated that under laboratory conditions

*Cyclops* sp. preys upon both anopheline and culicine larvae of the first and second instars in Ohio. Of more interest is the observation of Weed (1921) that small Entomostacea may have an indirect bearing on mosquito control in that they compete with larvae for food. It is perhaps pertinent that wherever numbers of *Elaphoidella* sp. and the circumtropical *Phyllognathopodus tigueri* were present in leaf axils on Viti Levu, mosquito larvae were absent. On the other hand, the abundance of these harpacticids may have been due to the absence of larvae, for when small crustaceans share the small amounts of water stored in leaf axils with mosquitoes (e.g., *Bryocyclops* sp., coll. nos. 293, 316), they tend to be few in numbers and the remains of their kind may sometimes be demonstrated in the alimentary tract of dissected larvae. The smaller Entomostacea in ponds undoubtedly furnish a source of larval food, but some species, notably among the ostracods, are too large to be captured by most mosquito larvae. The large *Stenocypris malcolmsoni* was so abundant about the edges of a large pond in Aitutaki (coll. no. 121) as to colour the water green, and here, in what appeared to be an ideal larval habitat notably free from predators and having a sufficiency of shelter in the form of marginal vegetation of the flexuous type, larvae of *Culex annulirostris* were very rare indeed. It is considered that the scarcity of mosquitoes may well have been a consequence of competition for food in this instance.

MALACOSTRACA. Freshwater amphipods of the genus *Gammarus*, so common in temperate countries of the Northern Hemisphere, are absolutely unknown from the tropics (Smith, 1909). Jardin (1859; ref. from Adanson, 1935) claimed that representatives of the genus are abundant in the Marquesas, but more recent observers have failed to substantiate this. *Talitrus*, which Jardin also reported, does occur, and may be encountered in damp places. *T. alluaudi*, which was taken alive from a tiny pool in a sheet of corrugated asbestos at Aneityum, is an almost cosmopolitan species of terrestrial habit. So too is the Oriental and Pacific *Orchestia anomala*, first recorded from Samoa by Stephensen (1947) and now listed from Viti Levu and Funafuti. *O. anomala* was collected from submerged marginal debris in a mangrove swamp near Suva, from amongst algal masses in semi-permanent ponds at Funafuti and from an all but dry transient pool on the latter island. According to Dr. D. E. Hurley (p.c., 1954) this species occurs from sea level to at least 600m, and is usually found associated with wet leaf mould and other such plant material. In both Fiji and Funafuti *O. anomala* was first noticed swimming through the water in obviously awkward fashion after having been dislodged by the movements of the larva dipper. The other amphipods listed in Table VIII were found in brackish water and belong to primarily brackish-water genera. My findings are thus in agreement with those of Adamson (1935) who found no strictly freshwater amphipods in the Marquesas and was unable to locate references concerning such amphipods from Pacific oceanic islands.

The northern freshwater isopods of the genus *Asellus* likewise have no relatives in the area in question. Although neither amphipods nor isopods featured in the Queensland collections, both orders occur in ponds in the temperate southern parts of Australia (Smith, 1909).

Turning now to the decapods, two species of crab of the freshwater and terrestrial genus *Sesarma* (Grapidae) were reported from Tahitian rivers by Seurat (1934). The only crabs found in mosquito larval habitats during this investigation were *Sesarma* aff. *rotundata* from a tree hole containing abundant larvae of *Aedes polynesiensis* at Nukunono, Tokelau Islands, and hermit crabs (*Pagurus* sp.) from a Samoan spray zone brackish pool having a heavy population of *Culex sitiens*. Freshwater shrimps and prawns are, on the other hand, of wide distribution and common occurrence throughout the South Pacific. Three wide-ranging representatives in each of the families Atyidae and Palaeomonidae extend from the Indian Ocean through Indonesia and the Pacific as far eastward as the Marquesas (Adamson, 1935). *Palaemon* aff. *debilis*, a predominantly coastal species known

TABLE VIII  
OCCURRENCE AND DISTRIBUTION OF MALACOSTRACA

SYSTEMATIC POSITION AND COLLECTION NUMBER	NO. OF TIMES COL- LECTED	LOCALITY									
		QUEENSLAND	SOLONIAN IS.	NEW CALEDONIA	NEW HEBRIDES	FJJI	TONGA	SAMOA	COOK IS.	GILBERT IS.	ELICE IS.
<b>AMPHIPODA</b>											
<i>Orchestia anomala</i> Chevreux Talitridae 49 <sup>1</sup> , 59 <sup>1</sup> , 60 <sup>1</sup> , 66 <sup>1</sup>	4				x				x		
<i>Talitrus alluaudi</i> Chevreux Talitridae (adventitious) 2 <sup>2</sup>	1			x							
<i>Paracalliope</i> aff. <i>fluvialis</i> (Thomson) Calliopidae 106, 267	2	x	x								
<i>Eriopis</i> sp. Gammaridae 143, 144	2	x									
<b>DECAPODA</b>										x	
<i>Scarma</i> aff. <i>rotundata</i> Hess Grapsidae 156	1										
<i>Pagurus</i> sp. Paguridae 191	1				x						
<i>Palaeomon</i> aff. <i>debelii</i> Dana Palaeomonidae 191	1					x					
<i>Palaeomon concinnus</i> Dana Palaeomonidae 1 <sup>1</sup> , 95	2		x	x							
<i>Cardina weberi</i> De Man Atyidae 93, 103, 32 <sup>2</sup> , 298, 50 <sup>1</sup> , 52 <sup>1</sup>	6	x	x	x							
<i>Caridina nilotica</i> (Roux) subsp. Atyidae 1 <sup>1</sup> , 3 <sup>1</sup> , 32 <sup>8</sup> , 34 <sup>5</sup> , 36 <sup>1</sup> , 37 <sup>0</sup>	7	x	x	x							
<i>Cardina typus</i> Milne Edwards Atyidae 31, 14 <sup>2</sup> , 15 <sup>1</sup> , 104, 369	5	x	x	x							
<i>Atya spinipes</i> Newport Atyidae 32 <sup>1</sup>	1	x									
<i>Macrobrachium</i> sp. Palaeomonidae 250	1	x									
<i>Cardina</i> sp. Atyidae 195, 362	2	x									
<i>Macrobrachium tolmerum</i> Rick Palaeomonidae 364	1	x									

from the Red Sea to the Tuamotu Group in the eastern Pacific (Dr. L. B. Holthuis, p.c., 1953), was present in the same pool on Savai'i from which hermit crabs were recorded, while *P. concinnus*, which has the same wide distribution as the previous prawn, was found in a freshwater pond in Fiji and near the mouth of a tidal stream at Aneityum, New Hebrides. Numerous large prawns, probably of this genus, were noted but not collected in still pools in mountain streams of Espiritu Santo and Guadalcanal. Such deep pools, continually flushed out by freshets and utterly without vegetation, never contained mosquito larvae. Adamson (1935) suggested that as so many of the Palaeomonidae ascend from the sea into brackish water, the species occurring in the Pacific may owe their wide distribution to a former marine habit.

Ortmann (1902) gave the range of the freshwater family Atyidae as approx. 43°S (near Christchurch, New Zealand) to 50°N (France), while emphasizing that these shrimps are chiefly confined to tropical and subtropical regions. The family is well represented and widely distributed in the tropical Pacific, where the occurrence of such exclusively freshwater animals on many strictly oceanic islands has been the subject of considerable attention. Ortmann considered the Atyidae of very ancient origin, and as having invaded fresh water during a period when a tropical climate prevailed throughout the world. Mumford (1936) felt that from this viewpoint the occurrence of atyids in the Marquesas supports the thesis that these islands are remnants of an old and extensive land mass.

Most authors have followed Ortmann (1894) in regarding the oceans as impassable barriers to the Atyidae. In an attempt to explain the puzzling occurrence of the family on so many oceanic islands, Edmondson (1929) investigated the possibility of these shrimps being transported in dried mud on the feet of birds.

Pointing out that the eggs do not lend themselves to dispersal in this fashion, being attached to the swimmerets of the females until hatched, he stated that shrimps which he embedded in mud mostly died, probably from oxygen lack, within 30 minutes; none remained alive after one hour. Edmondson, while feeling that his experiments lent no support to the hypothesis of transportation by birds, suggested that the dispersal of the Atyidae might have received material assistance from human migration. He pointed out that the secretive habits of these shrimps favour their being carried in fresh water or among moist plants. The thesis is of decided interest in view of the discovery of two widely distributed species, *Caridina typus* and *C. weberi*, in irrigation ponds on Ancityum (coll. nos. 104 and 105) in intimate association with the submerged basal portions of taro plants (*Colocasia antiquorum* or *C. esculenta*); for these food plants were long ago broadcast among the oceanic islands of the Pacific by Polynesian migrants.

Two of the present atyid collections were made from brackish sources. *Caridina weberi* was found among denuded tree roots near the mouth of a tidal stream at Anelgauhat, Aneityum (coll. no. 95), while *C. nilotica* was taken from a brackish pond on the Cook Highway near Buchan's Beach, Cairns, Queensland (coll. no. 345). The pond concerned was separated from the sea only by a few yards of sand. Weber (1892; ref. from Ortmann, 1891) likewise recorded two species of *Caridina* from brackish waters in Sumatra and Celebes. While Weber looked upon this as evidence for invasion from the sea, Ortmann himself (1891) believed it to be an instance of re-adaptation to brackish conditions on the part of fresh-water shrimps, pointing out that the genus *Caridina* is not a primitive one and that the most primitive atyids live exclusively in fresh water. Nevertheless, the fact that at least four species of *Caridina* invade brackish water suggests that in this genus at least, marine barriers may not be as effective as is generally held, and that appropriate marine research in the future may even indicate that some atyids enter the sea itself on occasion. Buxton (1930) quoted Dr. W. T. Calman as feeling that although the Atyidae "are doubtless a true and ancient fresh-water group . . . the genus and some of the actual species are so widely spread that he is tempted to suppose that they must at times enter the sea." In view of our shortage of information in this connection, and the fact that representatives of the family could be transported secreted in the moist inner leaf axils of such plants as *Colocasia*, it is surely unwise to regard the presence of these shrimps on oceanic islands as evidence of former continental connections.

Howard et al. (1912) quoted correspondents as believing that certain fresh and brackish water shrimps prey on mosquito larvae but that "their structure and small capacity prevent them from consuming any great numbers." More recently, McCay and Senior White (1941) drew attention to the control of culicine larvae by *Palaemon lamarrei* Milne Edwards in the galleries of a Bengal coal mine, into which adult mosquitoes were apparently drawn in the main air draught. It was postulated that the prawns themselves, all of which were quite small, had reached the 300-metre-deep galleries in moist sand which was used for stowing. Pools containing numerous prawns held few mosquito larvae, while the reverse held good in pools of more recent origin. Under laboratory conditions it was found that the small *P. lamarrei* consumed an average of almost three *Culex p. fatigans* larvae per day. McCay and Senior White suggested that the prawn in question, although eating far fewer larvae per day than such larvivorous fish as *Gambusia*, might be of value as a predator in shallow waters under conditions of darkness where a *Gambusia* introduction is impracticable. Laird (1947) reported that *Caridina typus* does not attack living mosquito larvae in New Britain, although this atyid scavenges upon dead larvae.

Experiments carried out at Suva indicated that *Caridina nilotica brachydactyla* De Man will stalk and feed upon culicine larvae under suitable conditions. On June 15, 1952, a prawn of this species from pond 1<sup>1</sup>, Nausori, was placed together

with five second instar larvae of *C. annulirostris* in 1 cm of water in a covered, vertical-sided glass dish. Within two hours one of the larvae had completely disappeared. On the following morning, seventeen hours after the commencement of the experiment, only two living larvae remained. A third, torn almost in two midway along the abdomen, was floating dead at the surface. By the middle of that afternoon, seven hours later still, another larva had been consumed as had the remains of the one killed previously. The last larva underwent ecdysis before it too was seized and eaten on the evening of June 18. A second of these prawns enclosed with a further five such larvae had killed and eaten four within 21 hours, but the remaining one was still alive five days later when the experiment was abandoned. In the case of a third atyid, five second instar—and five third instar larvae of *C. pipiens fatigans* were captured and eaten between 8 a.m. and 5 p.m. of the same day. In all three cases the prawns were fully grown. As they were enclosed with the mosquito larvae immediately after being brought back to the laboratory following their capture in the field, it cannot be objected that prior starvation was influencing them to seek food of a kind not normally resorted to.

The usual method of capture was for the shrimps to swim just beneath the surface film, disturbing surfaced larvae which promptly dived only to be seized as their movements betrayed them. One *C. nilotica brachydactyla* which was regularly fed mosquito larvae for three weeks finally became conditioned to moving to the larva pipette as soon as this was introduced into the dish and seizing the larvae as they entered the water! The shrimps very rarely succeeded in capturing pupae, because of the much greater difficulty in obtaining a grip on their rounded and more chitinous bodies.

Little can be said at this stage about the value of atyid shrimps as larval predators in the Pacific, beyond the bare fact that at least one Pacific species will capture and eat mosquito larvae. Although seven (35 per cent.) of the 20 habitats from which *Caridina* was recorded (Table VIII) were completely lacking in mosquitoes, all but one of these (14<sup>1</sup>, a rock pool on Ar<sup>1</sup>) had a faunal index of 3 or 4, indicative of a diverse macrofauna with a relatively high level of predation, while four (32<sup>1</sup>, 50<sup>1</sup>, 52<sup>1</sup>, 83<sup>1</sup>) were running streams, which seldom produce large numbers of mosquitoes in this Region (p. 158). Larvae were rare in four of the other 13 habitats, common in three and abundant in six. It is most probable that atyids are only rarely primarily responsible for the absence of mosquitoes from given habitats, but that these shrimps play a definite part—perhaps a more important one than has generally been realized—in the overall biological control of natural populations of mosquitoes.

**COLLEMBOLA.** Certain of the springtails are found on the surface film of still ponds. Two species have been recorded from this habitat in the South Pacific, *Isotoma palustris* Müller—which ranges from the British Isles (Clegg, 1952); to the Bismarck Archipelago and as far east as Mangaore (Seurat, 1934)—and *Sminthurides seuratii* Denis which occurs on the Lauer island (Seurat, 1931).

A species of *Drepanocyrthus* was collected from the surface of a coconut palm tree hole (hollowed out as a reservoir) at Nukunono, Tokelau Islands (coll. no. 152). Ants (workers minor of *Pheidole megacephala* Fabr.) were abundant on the trunk of this palm, and some of them were observed to venture out onto the marginal portion of the surface film to capture collembolans. *Sminthurides* sp. was plentiful on two pools, one of these brackish, at Tarawa (coll. nos. 306, 310), while a species of *Onychiurus* was abundant on the surface film of a small rock pool in the Nevaka River, Espiritu Santo (coll. no. 36). The determinations were made by Dr. J. T. Salmon, who regards all three species as new.

**PLACOPTERA.** *Clœon samoense* Tillyard, an endemic Samoan species, is the most easterly representative of the mayflies in the South Pacific, and this order is not known from Hawaii either (Germain, 1934). Lestage (1928) was of the opinion

that the genus *Cloeon* was widely distributed on an ancient Pacific land mass, citing the occurrence of closely related species in Indonesia, New Guinea, the Philippines and Australia.

TABLE IX  
OCCURRENCE AND DISTRIBUTION OF PLECTOPTERA

SYSTEMATIC POSITION AND COLLECTION NUMBER	COLLECTED	No. OF TAXA	LOCALITY								
			QUEENSLAND	SOLOMON IS.	NEW CALEDONIA	NEW HEBRIDES	FJJI	TONGA	SAMOA	COOK IS.	GILBERT IS.
PLECTOPTERA											
<i>Cloeon</i> spp. Bactidae 6, 76, 105, 176, 203, 205, 256, 268, 283, 326, 328, 329, 332, 336, 343, 348, 350, 353, 354, 359, 361, 363, 367, 368, 370, 371	"	26	x	x	x	x	x				
Undetermined Bactidae 80 <sup>c</sup>	"	1				x					
<i>Baetis</i> sp. Bactidae 36 <sup>c</sup>	"	1		x							
Undetermined Plectoptera 228	"	1		x							
<i>Atalophlebia</i> sp. Leptophlebiidae 345	"	1	x								
Undetermined Leptophlebiidae 355	"	1	x								

Nymphs of a species of this genus possibly referable to *C. samoense*, the development stages of which are as yet unknown, were collected from a ponded ditch at Apia, Upolu. *Cloeon* nymphs were also found quite widely in the New Hebrides, the Solomons and Queensland, while an undetermined representative of the same family (Bactidae) was plentiful on one occasion in Viti Levu (Table IX). Nymphs belonging to the genus *Baetis* were common under stones in a fast-flowing upland stream in Guadalcanal, and the family Leptophlebiidae was represented in the Queensland collections. As Table IX indicates these insects were of much more frequent occurrence in Queensland than in the remainder of the area under consideration.

Hinman (1934) reported the claims of several workers that mayfly nymphs are efficient destroyers of mosquito larvae, but Needham et al. (1935) were of the opinion that anyone who investigates these records "will find them so vague it is impossible to tell what kind of predatory larvae are intended, and it is highly probable that they do not refer to mayfly larvae at all."

From field observations in the Pacific there is no doubt whatsoever that nymphs of *Cloeon* spp. are of decided significance as mosquito predators. When inadvertently placed in the same collecting tube as mosquito larvae they attack these immediately, seizing even fourth instar larvae of *Anopheles farauti* and *Culex annulirostris* near the middle of the abdomen and biting the body almost through. The victim is then devoured rapidly, the head capsule and siphon often being discarded. On one occasion (coll. no. 256) a larva of *C. annulirostris* was under observation at the edge of a small pond when it was seen to be stalked and seized by a *Cloeon* nymph.

**ODONATA.** Dragonflies and damselflies, well known as powerful fliers, have colonized all parts of the South Pacific. While a certain amount of endemism is apparent, particularly in the high islands and among the weaker-flying Zygoptera, most of the species met with on the coasts and atolls are wide-ranging and virtually pantropical. Lieftinck (1953) considered all but one of the seven species of the order which he identified from Rarotonga, Cook Islands, to be recent immigrants which had reached the island with the aid of air currents. Zinneeman (1912), who went so far as to claim that hurricanes from the west have accounted for the distribution of the bulk of the insects of the south central Pacific, mentioned

(no reference) that large numbers of dragonflies have been known to be driven by strong winds 700 miles from Sumatra and Java to Cocos-Keeling Island. Van Zwaluwenburg (1913) has described how dragonflies were wont to appear at Canton Island in the Phoenix Group before suitable larval habitats were available at that atoll, and stated that these insects soon became established there following the creation of water catchments when airport facilities were installed. Even damselflies, belying their delicate appearance, find wide stretches of ocean no barrier. Thus *Ischnura aurora* occurs from India to Tahiti (Seurat, 1934). Fraser (1927) wrote of watching this species taking flight after emerging in Coorg, soaring almost perpendicularly until finally lost to sight, and was of the opinion that upper air currents beat it to immense distances.

Odonata were plentiful on all the islands visited where suitable larval habitats were available (Table X). Even on Bellona, which is quite without freshwater ponds, nymphs referable to the Zygoptera were found in numbers in a wooden dug-out water container (coll. no. 231) and in a rock pool in a lump of coral (coll. no. 232). Although no members of the order could be found at Nubunono

TABLE X  
OCCURRENCE AND DISTRIBUTION OF ODONATA

SYSTEMATIC POSITION AND COLLECTION NUMBER	NO. OF TIMES COLLECTED	Queensland	Solomon Is.	New Caledonia	New Hebrides	Fiji	Tonga	Cook Is.	Gilbert Is.	Ellice Is.	Tokelau Is.	
<b>Odonata</b>												
Undetermined Anisoptera	29, 31, 34, 7, 8 <sup>1</sup> , 57, 58, 67, 68, 72, 20 <sup>1</sup> , 112, 171, 176, 182, 190, 198, 199, 200, 31, 32 <sup>1</sup> , 209, 210, 211, 33 <sup>1</sup> , 35 <sup>1</sup> , 213, 226, 250, 261, 265, 266, 268, 269, 277, 285, 46 <sup>1</sup> , 305, 306, 309, 57 <sup>1</sup> , 310, 312, 321, 323, 330, 332, 336, 339, 345, 348, 349, 350, 351, 361, 85 <sup>1</sup> , 364, 368, 369, 370	60	x x x x x x x x x x x x x x x x x x									
Undetermined Zygoptera	6, 15, 16, 17, 20, 31, 31, 6 <sup>1</sup> , 9 <sup>1</sup> , 10 <sup>1</sup> , 57, 58, 63, 67, 68, 69, 72, 74, 170, 29 <sup>1</sup> , 171, 182, 190, 196, 32 <sup>1</sup> , 216, 231, 232, 10 <sup>1</sup> , 237, 217, 250, 268, 269, 271, 277, 291, 18 <sup>1</sup> , 50 <sup>1</sup> , 302, 305, 306, 309, 321, 73 <sup>1</sup> , 326, 327, 330, 331, 335, 336, 337, 339, 341, 349, 352, 358, 360, 361, 85 <sup>1</sup> , 363, 368, 370	63	x x x x x x x x x x x x x x x x x x									
<i>Psaltoda haeckeli</i> (Fabricius) Libellulidae	116, 121, 291	3		x x			x x		x x			
<i>Diaplocoelis bipunctata</i> (Brauer) Libellulidae	1 <sup>1</sup> , 31, 43, 65, 116, 118, 119, 122, 124, 116, 148	11	x x x			x x		x x				
<i>Ichnura a. aquora</i> (Brauer) Coenagrionidae	1 <sup>1</sup> , 45, 46, 116, 117, 118, 119, 122, 124, 144	10	x x			x x		x x				
<i>Ichnura</i> spp. Coenagrionidae	4 <sup>1</sup> , 141, 29 <sup>1</sup>	3	x x			x x		x x				
<i>Tramea</i> spp. Libellulidae	6, 148	2	x x			x x		x x				
<i>Anax</i> spp. Aeshnidae	17, 48	3	x x			x x		x x				
<i>Agriognathus</i> sp. Coenagrionidae	1 <sup>1</sup> , 11 <sup>1</sup> , 69, 138, 141, 144, 147, 149	8	x x			x x		x x				
<i>Hemicordulia oceanica</i> Selys Corduliidae	71	1	x			x		x				
<i>Ichnura torresiana</i> Tillyard Coenagrionidae	2, 28 (3) <sup>1</sup> , 91	3	x			x		x				
<i>Lestes cheesemanii</i> Kinnaird Lestidae	22, 35	2	x			x		x				
<i>Orthetrum</i> sp. Libellulidae	31	1	x			x		x				
<i>Agrionemis exsudans</i> Selys Coenagrionidae (?)	48, 71, (?)16 <sup>1</sup> , (?)103, 104, (?)105	6	x x			x x		x x				
<i>Lestes</i> sp. Lestidae	52, 53	2	x			x		x				
<i>Orthetrum caledonicum</i> (Brauer) Libellulidae	45, 46	2	x			x		x				

Dr. J. S. Armstrong informed me at Apia that the widespread dragonfly *Pantala flavescens* (Fabr.) breeds in brackish wells on another of the Tokelau Islands, Atafu.

New Guinea and Australia both have rich odonatid faunas, at least 345 species and subspecies occurring in the former country (Lieftinck, 1949) and 201 in the latter (Tillyard, 1926). Only 40 species and subspecies are known from the Bismarck Archipelago and 41 from the Solomons (Lieftinck, 1949), and the number of species present steadily decreases in the island groups to the east with each succeeding oceanic barrier. This trend is reflected by my figures for the various groups from New Caledonia and the New Hebrides eastward to the Ellice Islands (Table X), but it was unfortunately not possible to have any of the very numerous nymphs collected in the Solomons and in Queensland identified beyond their suborder. The most easterly specimens identified as to species were the circum-tropical *Pantala flavescens* and two other wide-ranging species known to extend to the easterly parts of French Polynesia (Seurat, 1934), the libellulid *Diplacodes bipunctata* and the damselfly *Ischnura aurora* which has already been referred to.

There is quite an extensive literature on the significance of larval odonatids as predators of mosquitoes. Hinman (1934), who briefly discussed the observations recorded up to that date, concluded that despite the voracity of odonatids under laboratory conditions their general habit of feeding in bottom mud precludes their being serious mosquito enemies in nature. Observations in the field and simple laboratory feeding experiments carried out in New Britain (Laird, 1947) indicated that although anisopteran nymphs are apt to consume larger numbers of larvae than the frailest nymphs of Zygoptera under favourable experimental conditions, the latter, not being so committed to bottom feeding habits and often feeding at the water surface, are of more practical significance as predators of the Culicidae and destroy relatively more anopheline larvae.

**PLECOPTERA.** Stoneflies, the larvae of which are generally found clinging to stones at the bottom of flowing streams, are well represented in Australia and New Zealand (Tillyard, 1926) but are unknown in tropical Polynesia (Mumford, 1936). A single larva referable to this order was collected from beneath a stone in a quiet backwater of an upland stream in Guadalcanal (coll. no. 32').

**ORTHOPTERA.** This order is usually regarded as thoroughly terrestrial and aerial. However, in Fiji there is a unique genus of but one species in which the hind tibia bear long and setose spines as a modification to an aquatic habit. This cricket, *Hydropedeticus vitiensis* Miall and Gilson (Trigonidiidae), was described from examples captured dancing on the surface of the water in a clear and rapid branch of the upper Navua River, Viti Levu (Miall and Gilson, 1902). It was subsequently reported from wet boulders in rivers and near waterfalls by Lever (1941). This species figured in two of our Fijian collections (coll. nos. 40, 52'), its behaviour and habitat being as described by Miall and Gilson. Buxton (1935) referred to a Samoan cricket of somewhat similar habits, *Anaxipha hopkinsi*. This species is not adapted for water-skating, but nevertheless swims easily over the surface of rushing water. Grasshoppers which frequent moist areas in the vicinity of water not infrequently have limited swimming abilities, for example *Hydrotettix cheesmanae* Uvarov and *H. apera* Uvarov which occur in Tahiti (Cheseman, 1927).

Water bugs of the genus *Rhagovelia* (Hemiptera: Veliidae), which are specially adapted to life on the surface of torrents, do not extend south or east of the Solomons. It is of considerable interest that their place in an otherwise un-utilized ecological niche has been filled in Fiji by representatives of so unlikely an order as the Orthoptera.

**HEMIPTERA.** As Table XI indicates, the small pond skaters of the genus *Microvelia* and water striders of the genus *Limnogonus* were plentiful in all localities visited from Queensland to the Cook Islands. Representatives of both genera also occur in Tahiti (Lundblad, 1935). The only islands where they were not recorded despite the presence of suitable habitats were Tarawa and Funafuti, while

of the relevant references were summarized by Hinman (1934), who considered that notonectids are the most voracious of all the aquatic Hemiptera as regards mosquito destruction. Frick (1949) undertook feeding experiments with *Microvelia capitata* Guérin in the Panama Canal Zone, successfully rearing four generations in the laboratory on anopheline larvae (*An. albimanus* Wied.) only. He reported that the newly emerged "pinhead" larvae are destroyed by early instars of this bug; imagines of which suck the body fluids of second, third and even fourth instar anophelines. Although veliids very frequently came under observation in the field during the present project, they were only observed to attack mosquitoes on a single occasion (coll. no. 35, Espíritu Santo). A species of *Microvelia* was present in very large numbers on the surface of this water body—a rock pool—which supported abundant larvae of *Culex fuscipes*. Many adults of this mosquito had alighted upon the water to oviposit, each of them being surrounded by numerous veliids which, as soon as the mosquito flew off, dived in and began attacking the newly deposited egg raft. The rate of destruction was such that few of the eggs could have survived until hatching took place.

Pruthi (1928) and Tounianoff (1941) observed in India and Indo-China respectively that the belostomatid *Sphaeroderma annulatum* Fabr. readily attacks mosquito larvae. The latter author noted that both culicines and anophelines are preyed upon. He stated that a single female bug reared in the laboratory destroyed 1,411 larval *Anopheles* in two months, and believed that *S. annulatum* exhibits a preference for mosquito larvae as food in nature and is of decided importance in the biological control of these insects in marshy places. However, although an unidentified species of *Sphaeroderma* was plentiful in three of the Queensland collections (nos. 338, 339, 350), *C. annulirostris* was abundant in the first of these and *An. annulipes* and *An. b. bancroftii* in the last.

The majority of aquatic predators may be conditioned to an exclusive diet of mosquito larvae under laboratory conditions, but in most cases there is no evidence that selective feeding takes place in nature. It is considered that almost all hemipterans living in ground pools of one kind and another play a part in the natural control of mosquito breeding, but that the majority of them are not of particular individual importance.

Artificial introductions of notonectids into containers may give spectacular results. Thus Dempwolff (1901) introduced back swimmers into 17 water tanks in a New Guinea settlement and completely eliminated mosquito breeding in these in one week. Unfortunately, the habitat preferences of notonectids are strongly biased in the direction of surface water. Although the adventitious occurrence of these insects in containers is noticed from time to time, and is apt to be correlated with the absence of Culicidae—thus *Anisops* sp. was extremely plentiful in a concrete trough (coll. no. 30<sup>1</sup>) lacking mosquitoes at Mbalau, Fiji, while another representative of the same genus was abundant in a 4½ gallon drum (coll. no. 44<sup>1</sup>) from which mosquitoes were absent at Sikaiana—such occupations tend to be of brief duration. When the food supplies are exhausted the bugs fly off to other habitats. A larval predator is obviously of little practical significance if it has to be reintroduced into each and every container each time this is repopulated by mosquitoes.

Attempts by Dempwolff to employ notonectids to control breeding in transient pools were unsuccessful because of the rapidity with which these dried up, and Davis (1949) reported the failure of an artificial introduction of *Anisops cleopatra* into Rarotonga.

Perhaps the most potentially useful of all known aquatic hemipterans is the Malayan (*Cercotmetus* sp.) = *Cercometes* sp. discussed and illustrated by Williamson (1949). This wingless and sluggish water scorpion (Nepidae) feeds almost exclusively on mosquito larvae in nature, a full-grown one keeping an area of

about five to six yards radius around itself almost clear of larvae. Its flightlessness prevents its leaving natural ponds once introduced into them, but also operates against its natural dispersal. Williamson (1949) mentioned that the insect is of rare occurrence in its native Malaya. While it is obviously not fitted for life in transient pools, it might prove worthwhile to import this *Cercometus* into the malarious islands of Melanesia if only to introduce a further biological hazard to be faced by those mosquitoes which, particularly under dry season conditions, utilize the more permanent types of ponds as larval habitats.

**NEUROPTERA.** Alder flies and dobson flies, which are represented by only a few rare species in Australia (Tillyard, 1926), are insects of flowing rather than static water. They did not figure in the Queensland collections, and are unknown in the tropical Pacific. Neuropterous larvae are often highly predaceous, and Lauborn (1923), who noted their abundance in certain Malayan ponds altogether lacking in anopheline larvae, fed mosquitoes to them in the laboratory. He reported that when confined in basins the neuropterous larvae in question devoured one another rather than the Culicidae with which they were amply supplied.

**TRICHOPTERA.** This order is not known to the east of Samoa, which has a single endemic species (Buxton, 1935). Undetermined caddis flies of the families Hydropsychidae (coll. no. 50<sup>1</sup>) and Hydropsyliidae (coll. no. 80<sup>1</sup>) were recorded from two streams in Viti Levu, while two further records were obtained from a Guadalcanal hill country stream (coll. no. 32<sup>1</sup>) and from a ponded stream in Queensland (coll. no. 360). Larval Trichoptera are relatively inactive, many of them manufacturing conical nets to catch micro-organisms brought to them by the flowing water in which they are usually found. While a Canadian species has been known to trap larvae and pupae of *Aedes* sp. in its net (Twinn, 1931), the habitat preferences and manner of feeding of caddis larvae weigh against their having any significant biological interaction with mosquitoes.

**LEPIDOPTERA.** Caterpillars of certain moths have aquatic habits. With the exception of *Nymphula fluctuosalis* Zeller, which is established in Hawaii (Williams, 1944), there are no records of these insects from the Pacific. The larvae of *N. fluctuosalis* attack the leaves of water lilies and also cause damage to rice plants (Williams, 1911). They were not found to the east of Australia, but were common about the pads of *Nymphaea gigantea* in a Queensland pond (coll. no. 367). Special search might perhaps reveal their presence in Pacific islands where suitable food plants are available.

**DIPTERA/CULICIDAE.** The distribution of the Culicidae in the Pacific is far better known than is that of any of the other organisms utilizing aquatic habitats. Buxton (1935) tabulated the various subgenera of the region so as to draw attention to the family's steadily decreasing representation in an easterly direction across the ocean. Table XII is based on that of Buxton, incorporating further data collected during the last 20 years. Our collection records are summarized in Table I, the full names of the 54 species referred to therein being listed hereunder.—

*Bironella*

*B. (Brugella) hollandi* Taylor

*Anopheles*

*An. (Anopheles) b. bancroftii* Giles

*An. (Anopheles) stigmaticus* Skuse

*An. (Myzomyia) annulipes* Walker

*An. (Myzomyia) farauti* Laveran

*An. (Myzomyia) punctulatus* (Dönitz)

*An. (Myzomyia) solomonis* Belkin et al.

*Tripterooides*

*T. (Rachisoura) matthesoni* Belkin

*T. (Mimeteomyia) folicola* Belkin

TABLE XII  
THE KNOWN DISTRIBUTION OF THE SUBGENERA OF THE CULICIDAE  
FROM THE SOLOMON IS. EASTWARDS.

Based on Buxton, 1935, with additions since that time. *Toxorhynchites* (Fiji, introduced) not included. Unconfirmed reports and records of introductions which may have died out, indicated by a question mark.

SCIENTIFIC	LOCALITY
<i>Stegomyia</i>	
<i>Culex</i>	
<i>Ochlerotatus</i>	
<i>Aëdomyia phus</i>	
<i>Finlaya</i>	
<i>Coquillettidia</i>	
<i>Mimeteomyia</i>	
<i>Uranotaenia</i>	
<i>Gonatocera</i>	
<i>Tripteroidea</i>	
<i>Aëlonia</i>	
<i>Lophoceralomyia</i>	
<i>Myzomyia</i>	
<i>Aëdes</i>	
<i>Mochlogenes</i>	
<i>Ncoocles</i>	
<i>Mucidus</i>	
<i>Atallyntrum</i>	
<i>Arinigeres</i>	
<i>Bankainella</i>	
<i>Brugella</i>	
<i>Covshrella</i>	
<i>Culicomyia</i>	
<i>Etorofitomyia</i>	
<i>Harpagomyia</i>	
<i>Hodgesia</i>	
<i>Futzia</i>	
<i>Mansonioides</i>	
<i>Rachisoura</i>	
<i>Skusea</i>	
	Solomon Is.
	New Caledonia
	Fiji
	Tonga
	Samoa
	Cook Is.
	Ellice Is.
	Society Is.
	Marquesas
	Pitcairn I.

- A. (Stegomyia) aegypti* L.
  - A. (Stegomyia) albolineatus* (Theobald)
  - A. (Stegomyia) marshallensis* Stone and Bohart
  - A. (Stegomyia) pernolutus* Farner and Bohart
  - A. (Stegomyia) polynesiensis* Marks
  - A. (Stegomyia) pseudoscutellaris* (Theobald)
  - A. (Stegomyia) quasiscutellaris* Farner and Bohart
  - A. (Stegomyia) s. scutellaris* (Walker)
  - A. (Stegomyia) tongae* Edwards
  - A. (Aedimorphus) alboscutellatus* Theobald
  - A. (Aedimorphus) vexans* Meigen var. *nocturnus* (Theobald)
  - A. (Aedes) lineatus* Taylor
- Culex*
- C. (Luzia) halifaxi* Theobald
  - C. (Mochlogenes) femineus* Edwards
  - C. (Lophoceratonyia) cylindricus* Theobald
  - C. (Lophoceratonyia) fraudatrix* Theobald
  - C. (Culicomyia) papuensis* (Taylor)
  - C. (Culicomyia) pullus* Theobald
  - C. (Culex) allinervus* Edwards
  - C. (Culex) annulirostris* Skuse
  - C. (Culex) basicinctus* Edwards
  - C. (Culex) bitaeniorhynchus* Giles
  - C. (Culex) mimulus* Edwards
  - C. (Culex) pacificus* Edwards
  - C. (Culex) pipiens* L. var. *fatigans*, Wiedemann \*
  - C. (Culex) sitiens* Wiedemann
  - C. (Culex) squamosus* Taylor
  - C. (Culex) whitmorei* Giles
  - C. (Neoculex) aff. *pseudomelanonota** Theobald
  - C. (Acallyntrum) perkinsi* Stone and Penn
- Corethrella*  
*Corethrella* sp.

Representatives of *Aedes* (*Stegomyia*) are the most widely distributed mosquitoes of the region, occurring everywhere from Australia and New Guinea eastwards to the Marquesas and Pitcairn Island. The complex of closely related species of the *scutellaris* group of *Aedes* (*Stegomyia*) includes the chief vectors of *Wuchereria bancrofti* in Polynesia and Fiji (Iyengar, 1951), while at least one of its members *A. polynesiensis*, can transmit dengue virus under laboratory conditions (Rosen et al., 1954). These mosquitoes utilize containers as larval habitats. Their habits thus favour their dispersal by human agency, and they have reached even such remote islands as those of the Tokelau and Marquesas. Rosen (1954a) presented an analysis of historical data which strongly suggests that *A. polynesiensis* has reached the Marquesas since the beginning of European influence in Polynesia. Marked endemism is apparent within the *scutellaris* complex. Several of the species are difficult to separate from one another as larvae, although the characters upon which the adults are differentiated are quite well marked. The following representatives of the complex occur in the islands of the South Pacific, each name being followed by the most recent pertinent reference.

*A. polynesiensis* Marks (Fiji to the Marquesas) Marks, 1951a

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\* The name *Culex pipiens fatigans* Wied. is adopted in this paper in preference to *Culex fatigans* Wied., the name by which this form has hitherto been known. The authority for this change is to be found in Mattingly et al. (*Trans. R. ent. Soc. Lond.*, 102, 331–382, 1951 (R.A.E., (B) 40, 62–67))

- A. tongae* Edwards (Tonga, whence it apparently accompanied Polynesian migrants to Sikaiana) Buxton and Hopkins, 1927  
*A. pseudoscutellaris* (Theobald) (Fiji) Marks, 1951a  
*A. horrescens* Edwards (Fiji) Edwards, 1935  
*A. marshallensis* Stone and Bohart (Marshall and Gilbert Islands) Bohart and Ingram, 1946  
*A. pernotatus* Farmer and Bohart (New Hebrides) Farmer and Bohart, 1944  
*A. s. scutellaris* (Walker) (New Hebrides) Stone, 1947 (Rennell and Bellona) Herlein

*A. quasiscutellaris* Farmer and Bohart (Solomons) Farmer and Bohart, 1944

Recent hybridization studies have shown that certain of the above names should perhaps be accorded only subspecific rank. While Woodhill (1950) demonstrated that *A. pseudoscutellaris* and *A. s. scutellaris* are completely isolated genetically, he had previously (1919) shown that female *A. s. scutellaris* and male *A. s. katherinensis* Woodhill (Northern Territory, Australia) give a completely sterile cross although the reciprocal cross is sterile; indicating (1950) that back crosses of  $F_1$  hybrids made with both parents are fertile with the exception of hybrid males crossed with *katherinensis* females. Perry (1950a) reported that *A. s. scutellaris* ( $= A. hebridus$ ) and *A. pernotatus* hybridize in the laboratory only with great difficulty and that no apparent intergrades are found in Espiritu Santo where both mosquitoes occur. He thus considered them to be true morphological species, but Woodhill (1950), pointing out that Perry used only small numbers of individuals in his crossbreeding experiments and that he himself had experienced the same difficulty with small numbers of *A. s. scutellaris* and *A. s. katherinensis*, was inclined to think that the specific status of *A. pernotatus* should be regarded as in doubt until more extensive hybridization studies have been undertaken. I would毫不犹豫地 agree with Perry in this issue, for *A. s. scutellaris* and *A. pernotatus* are sharply differentiated on larval as well as adult criteria, and on three occasions in Anceityum we collected larvae of both species from the one breeding place (coll. nos. 78, 79, 109). Finally, Woodhill (1954) demonstrated that *A. polynesiensis* (from Tahiti) and *A. pseudoscutellaris* are not genetically isolated, and suggested that "it would perhaps be more accurate to consider the two forms as sub-species, rather than to give them full specific rank."

For the purposes of the present account the various members of the *scutellaris* complex are regarded as separate species, without prejudice to the questions of geographical and genetical isolation which are still under investigation by Woodhill.

In the whole region under consideration the New Caledonian area is the only major one where the *scutellaris* complex is not represented, the introduced *A. aegypti* being the only *Stegomyia* found there. This latter mosquito, a major vector of the virus of dengue fever, has been recorded as far east as Pitcairn Island (Edwards, 1924). There is an unconfirmed record of "*Stegomyia scutellaris*" from Pitcairn Island (Theobald, 1907), which Marks (1951) thinks is probably referable to her *A. polynesiensis*.

Species of *Culex* (*Culex*) are next most widely distributed. *C. pipiens fatigans* and *C. annulirostris*, both of which are able to develop in containers and can thus take advantage of inter-island communications, being found from Australia to the Society Islands. The former species has reached as far eastwards as the Marquesas, while the latter is not known from that group but is established in the Tuamotu Islands (Marks, 1951). The distribution of *C. sitchensis*, which breeds in brackish water including that in artificial containers, was given by Edwards (1932) as all coasts from Somaliland and Ceylon to South Queensland and Fiji. Bohart and Ingram (1946) expressed doubts as to whether the African and Indian records are actually referable to this species, and quoted records extending the eastward limits of *C. sitchensis* to the Wallis Islands and Samoa (Tutuila). *C. jejsoni* Theobald is a synonym of *C. sitchensis*, but Buxton and Hopkins (1927) stated that records

under the former name from Samoa refer to *C. annulirostris*. However, two of my collections from Apia, Upolu, included undoubtedly *C. sitiens* (coll. nos. 173, 181). The species was not found further east nor in Tonga, although T. M. P. Kuli Helu of the Tongan Public Health Department informed me at Nuku'alofa that it is found there from time to time especially in the brackish marshes about Fanga Uta Lagoon. Galliard et al. (1919) reported that *C. sitiens* occurs, although rarely, in Tahiti, but Rosen (1953) referred the brackish water breeder in question to *C. littoralis* Bohart, a closely related species described from the Mariana Islands (Bohart, 1946).

*Culex (Culex) marquesensis* Stone and Rosen is indigenous to the Marquesas, occurring on five of the six inhabited islands (Stone and Rosen, 1953), while two other mosquitoes, *Culex (Culex) atriceps* Edwards and *Aedes (Ochlerotatus) edgari* Stone and Rosen, are restricted to the Society Islands. *Aedes vexans nocturnus* is not yet known from that group, but occurs as far east as the Ellice Islands (Buxton and Hopkins, 1927; Laird, 1955a). There is also an unconfirmed record possibly referable to this species from Rarotonga, Cook Islands (McKenzie, 1925). *A. vexans* does not lend itself to distribution through human agency in the larval state, but there are grounds for postulating that inter-island migrations of imagines may have taken place (p. 9).

The widespread *kochi* complex of *Aedes (Finlaya)* is represented by *A. samoanus* in Samoa and Tonga and by *A. fijiensis* in Fiji (Marks, 1947). The type material of *A. fijiensis* Marks was collected from *Pandanus* leaf axils, while Paine (1913) stated that leaf axils of *Pandanus* spp. and *Alocasia indica* are utilized as larval habitats by this species (= *A. kochi*). We neither collected *A. fijiensis* nor made any special efforts to locate larval habitats of this insect. The Fijian *Finlaya* recorded herein differs substantially from the last-named species as described by Marks (1947), and its larvae were found only in the leaf axils of *Freycinetia milnei*. It is considered to be a new species, and will be described as such in due course.

A single endemic representative of the subgenus *Culex* has been described from Samoa. *Culex (Culex) samoensis* (Theobald) is known only from three wild-caught females, and its affinities were considered by Edwards (1924, 1932) to lie with the *bitaeniorhynchus* series. Buxton and Hopkins (1927) sought unavailingly for this insect in Samoa and concluded that it must be extremely rare or that it breeds only in some specialized place. Another member of the *bitaeniorhynchus* series, *Culex (C.) albinevris*, is native to Fiji where its larvae are to be found amongst filamentous green algae at the edges of streams or in taro irrigation (Paine, 1943). *C. albinevris* has recently been recorded from Fox Island, Tonga (Helu and Ha'unga, 1952). The members of the *bitaeniorhynchus* group exhibiting a decided preference for larval habitats rich in green algae (p. 141), and frequently utilizing the edges of streams as breeding places, it is suggested that an intensive search of this ecological niche in Samoa might well reveal the as-yet unknown developmental stages of *C. samoensis*.

The species thus far considered include all those known from the islands east of Fiji. In Fiji itself we find the most easterly known representatives of four subgenera strongly represented to the west. There are two endemic species of *Uranotaenia*, *U. colocasiiae* Edwards and *U. painei* Edwards, both of which are most commonly encountered on the smaller islands of the group (Paine, 1943). Neither species was collected during these studies, in which numerous *Colocasia* leaf axils were searched on Viti Levu where the former mosquito is known to occur, although not commonly (Paine, 1913). *Mansonia (Coquillettidia) crassipes* van der Wulp, a marsh-breeding species the larvae of which have the specialized habits of the genus, is known from the Oriental Region to Fiji (Edwards, 1924). The only record of the larvae of this insect from Fiji is that of Lever (1913), who collected them from the roots of a sedge—identified by Lever (1944) as *Eleocharis* sp. near *articulata* Steud.—in a marsh at Nandi. *Tripteroides (Triteroides) purpurata*

Edwards (coll. nos. 317, 325) is endemic to Fiji, whence is also known a crab-hole-breeding *Aedes* referred to by Amos (1947) as *A. (Levua) geoskusea* Amos (1941). I have been unable to trace any reference to a proper description of this mosquito. It is possibly referable to the subgenus *Geoskusea* which is represented in the New Hebrides and Solomons.

As to recent introductions, *Aedes (Ochlerotatus) vigilax*, a common insect in salt marshes in Queensland and New Caledonia, was first recorded from Fiji by Lever (Paine, 1943). The record was based on adults captured in buildings in Suva during March, 1940, and identified by the late Dr. F. W. Edwards. This species has not since been reported from Fiji, and it is considered probable that the examples then collected had arrived on a vessel or flying boat from the west but failed to become established. *Aldomyia catalita*, a species common in Australia, was recorded from the Nandi River, Viti Levu, 1943 (as *Ay. venustipes* Skuse) (Lever, 1944). It was found again in the same locality in 1948, and it was felt that an introduction had been made by aircraft arriving at Nandi Airport from Australia (Unpublished Report, Fijian Medical Department, 20th August, 1948). Control measures were directed against the breeding places, and larvae of this species have not since been found in Fiji. Finally, *Toxorhynchites* (= *Megarhinus*) *splendens* Weid. was deliberately introduced into Fiji from Java in 1931 and 1932 as a predator on *A. pseudoscutellaris* (Paine, 1931). This useful insect is now established in many parts of the Group (Paine, 1943). There is no record of its introduction into Tonga, but Hele and Ha'onga (1952) claimed to have captured adults on Foa Island in that Group. This record, like that of *C. albivittis* from Foa by the same authors, must await confirmation.

The only other endemic species known from east of the New Hebrides is *Tripteroides (Mimeteomyia) rossmanni* Edwards, which is restricted to the island of Rotuma some 400 miles north of Viti Levu (Edwards, 1929).

The most recent summary of the mosquitoes of the New Hebrides is that of Perry (1946), who listed 18 species from Espiritu Santo. Five of the species found further to the east occur, *Culex annulirostris*, *C. pipiens fatigans* (= *C. quinquefasciatus* Say), *C. siensis* (= *C. japonicus* Theob.), *Aedes vexans nocturnus* (= *A. vexans* Meigen) and *A. aegypti*. There are three endemic species, *Culex (Mochtaghes) femineus*, *Culex (Culex) pacificus* and *Aedes (Stegomyia) perniciosa*. Of the remaining ten mosquitoes *Tripteroides (Mimeteomyia) melanesiensis* (= *T. caladenica* insofar as earlier records from the New Hebrides are concerned) occurs elsewhere only in New Caledonia, another—*Aedes (Geoskusea) daggyi* Stone and Bohart—is also found in the Solomons (Stone and Bohart, 1911), while *Cranotaenia sibida* Taylor, if indeed the *Cranotaenia* of the New Hebrides belongs to this species, was described from Queensland. A member of the *btaeniorhynchus* complex of *Culex* (*Culex*), *C. basicinctus*, occurs in New Caledonia and Australia, and *C. (Lophoceratoma) fraudatrix* is found in Australia, the Belep Islands (Laird, 1951a), the Solomons and other islands to the northwest. *Mansonia (Coquillettidia)* occurs, the species concerned being listed by Perry (1946) as *M. xanthogaster* (Edwards). There is some uncertainty as to whether the New Hebridean *Mansonia* is actually referable to this species, which Edwards (1924) stated was the Australian representative of *M. brevicellulus*, or to *M. crassipes*, which occurs in Fiji and New Caledonia. *Aedes (Stegomyia) s. scutellaris*, the furthest outpost of which is Aneityum, is found in New Guinea and also in the southwestern Polynesian outliers of the Solomons, and *Anopheles (Myzomia) fumiferi* and *Aedes (Aedes) hincatus* (= *A. fumiferus ornatus*) both occur in the Solomons, Queensland and New Guinea. Perry stated that he collected larvae of *A. vigilax* from a salt water pool on Espiritu Santo in 1911. This is the sole record of the species from the New Hebrides, and Perry (1946) considered that an introduction had probably taken place from Noumea, New Caledonia. From

the lack of subsequent reports it seems likely that *A. vigilax* failed to become established.

One further mosquito, *Tripteroides (Mimeteomyia) folicola*, was collected during the present studies, this species being recorded from the hill country of Espiritu Santo (coll. no. 37). Mills (1954) reported three species from Futuna in the southern New Hebrides, *Aedes s. scutellaris* (= *A. s. hebridus*), *Culex sitiens* and *Tripteroides (Mimeteomyia) coheni* Belkin. The first two species, also *A. vexans nocturnus* and *T. melanesiensis*, were collected at Futuna by my wife and me. *T. melanesiensis* was abundant, and it is considered that Mills' record of *T. coheni* should be referred to the former species. *T. coheni* is only known from the Solomons (Guadalcanal, New Georgia, Treasury Islands) (Belkin, 1950). It is a rare insect, and it would be surprising indeed for it to be encountered in the southern New Hebrides on a little-visited island so far from its known range. Bohart and Ingram (1946) referred to the New Hebridean mosquito identified as *Aedes s. hebridus* by earlier authors as *A. zonatus* (Walker). Both names were recognised as synonyms of *A. s. scutellaris* by Stone (1917).

Notes dealing with our material from New Caledonia and the Belep Islands have already been published, together with a review of relevant literature (Laird, 1954a). The endemic element in this fauna is a small one. A species of *Aedes (Mucidus)* described and known only from New Caledonia, *A. kermorganti* (Laveran), is of doubtful validity. Edwards (1922) suggested that this might merely be a form of *A. alternans* (Westwood), an Australian species which also occurs in New Caledonia. Dr. E. N. Marks informs me (p.c., 1951) that the mosquito identified in my paper as *Culex (Neoculex) pseudomelanonotia* Theobald is not really referable to this Australian species and will shortly be described as new. Williams (1913a) was the first to record "*C. pseudomelanonotia*" from New Caledonia. No adults were collected during our visit to the island, and the larvae were found to differ in several respects from Australian *pseudomelanonotia* as already described (Laird, 1954a). *Tripteroides caledonica* has been regarded by earlier investigators as occurring in both New Caledonia and the New Hebrides. However, Belkin (1955) showed that this species is restricted to New Caledonia, where it breeds only in the pitchers of *Nepenthes*, and that the mosquito which I recorded as *caledonica* from Ait (Laird, 1954a) is referable to *T. melanesiensis*, which ranges from New Caledonia to the New Hebrides.

The remaining 11 mosquitoes now known from this area all occur outside of New Caledonia, one of them, *Culex (Culex) bitaeniophryneus*, apparently being a recent importation from Australia (Laird, 1954a). *Aedes argypti*, *A. vexans nocturnus*, *Culex annulirostris*, *C. sitiens* and *C. pipiens fatigans* extend far to the east as already indicated, and *Mantonnia crassipes* also occurs in Fiji. *Aedes (Finlaya) notoscripta*, an Australian container-breeding species, the establishment of which in some of the wetter parts of the South Pacific has been made possible through commerce. The appearance of *Aedes vigilax* (a very common coastal mosquito of eastern Australia and New Caledonia) in Fiji and the New Hebrides has been noticed in the preceding pages. *Culex fraudatrix* (thus far unknown from New Caledonia itself but occurring on Ait, Belep Islands) and *C. basicinctus* both occur in Australia and the New Hebrides, the former species also being found in the Solomons. The mosquito fauna of the Loyalties is much more limited than that of New Caledonia. During three days of intensive collecting at Uvea my wife and I were able to find but one species, *C. annulirostris*. It was not possible for us to visit the other two islands of the Group, Lifu and Maré, from the former of which Cheesman collected *Tripteroides melanesiensis* according to Belkin (1955).

It is not intended to discuss the extensive mosquito faunas of Australia and the Solomons herein. At least 79 species are now known to occur in the latter group (Belkin, p.c. 1951). Many undescribed species were collected there by wartime malaria control units, and Belkin is dealing with these in a series of detailed

papers. Our collections in the Solomons and in Queensland were made with the primary object of obtaining data on larval ecology for comparison with those from the perimeter of the malaria belt and the more easterly islands. Due to considerations of time, attention was virtually confined to surface water larval habitats in Queensland. Several of the locality records given herein are new. Lambert (1931) had previously recorded *Aedes s. scutellaris* (= *A. variegatus*) and *A. albilabris* from Bellona. Both these species were collected on the island, as also were *Aedes albolineatus*, *Culex fraudatrix* and *C. halifaxi*. As regards Rennell, Lambert's records of *A. s. scutellaris*, *A. albilabris* and *C. fraudatrix* (= *C. hilli* var. *buxtoni*) were confirmed, and *Anopheles farauti* was found in the same area (coll. no. 230) where Black (1952) discovered larvae. Three species not previously known from Rennell were also collected, *A. albolineatus*, *Culex annulirostris* and *C. squamosus*. *Aedes lineatus* and *Culex annulirostris* were found at Sikaiana, in addition to the mosquitoes — *An. farauti* and *Aedes tongae* already known from the aroll. There does not appear to be any previous published record of *Culex whitmorei* from Australia, where this species was found quite commonly in the Cairns area and on the Atherton Tableland, but Mr. D. J. Lee (p.c., 1954) informs me that it has been collected on a number of occasions in northern parts of the country.

One of the most interesting of the new locality records from the western Pacific concerns several adult mosquitoes which were captured while biting during the study of a larval habitat (coll. no. 202) at Ilu Farm, Guadalcanal. These were identified by Dr. E. N. Marks as *Aedes vigilax*, a species not previously known from the Solomons. There were tidal reaches of the Tenaru River, which might conceivably have been serving as the larval habitat, within a mile of the collecting station. There was heavy air traffic between Australian and New Caledonian airfields where *A. vigilax* is a pest, and Henderson Airfield, a few miles from Ilu Farm, during the Pacific War. Since then numerous ships from ports where this mosquito abounds have called at the mouth of the Tenaru River to load timber. This record, when taken in conjunction with the earlier ones from Suva and Espiritu Santo, suggests that the species, which is a strong flier and always very abundant about ports and airfields in the vicinity of its breeding grounds, is in process of expanding its area of distribution in the Pacific. Further support for this contention is to be had from the fact that in 1952 *A. vigilax* adults were taken in the vicinity of an inland brackish lake at Mildura, Victoria, near a wartime airfield (Marks, p.c., 1954).

The general picture of mosquito distribution in the South Pacific, then, is of the cosmopolitanism of a relatively few species which, through their choice of larval habitats, have been able to avail themselves of transportation by human agency; and of a limited degree of endemicism on the higher of the oceanic islands associated with a progressive reduction in generic and subgeneric representation with increasing distance from Australia and the large islands near that continent. The part played by human transportation in the dispersal of the Culicidae in this region is considered to be a very important one indeed. *Stegomyia* has been particularly favoured in this respect, as have such domestic species as *Culex pipiens fatigans*.

Many of the introductions, such as that of *Aedes tongae* into Sikaiana, presumably took place in pre-European times. For certain of the more recent ones we have only hearsay authority. A typical account is that of Grant (1933) who stated that old European residents on Nauru believed that "*Stegomyia fasciata*" came to the island with "a recruitment of Kanaka labour from the Marshall Group about 20 years ago." "*Stegomyia fasciata*" is of course a synonym of *Aedes aegypti*, which occurs in the Marshalls (Bohart and Ingram, 1946). However, the species was also recognised from Nauru by Grant under another synonym, *A. argenteus*. If this author was indeed dealing with two species of *Stegomyia*, the probability is that the other one belongs to the *scutellaris* group. It would thus be of decided

interest to ascertain whether or not this is so, and if so whether the species present is referable to *A. marshallensis*. Stone and Bobart.

A series of events leading up to the introduction of mosquitoes into an isolated and formerly waterless Pacific atoll was traced out by l'Abbé Rougier. This author (1922) described how when Cook visited the Line Islands in 1777 he noted that Christmas Island was without vegetation apart from a few shrubs. Cook had wells dug, but found no water. Sixty years later the crew of the brig "Briton" reported the presence of a harsh, brackish water, and in 1858 wells which were dug yielded water sufficiently good for horses and mules being transported on another brig. Thirty years later coconuts were planted, and from 1920 onwards drinkable water has always been able to be obtained from the atoll. Vegetation continued to flourish and by 1915, wrote Rougier, Cook's few shrubs had become legion. The first mosquitoes arrived in 1917, by way of a barrel of drinking water brought to the atoll from Tahiti. Rougier (1926) described how he took prompt action against them, ordering the overturning of all water receptacles, the treatment of all wells in the infested part of the island with kerosene, and the evacuation of the area for 15 days. A subsequent inspection showed that none of the insects had survived, this happy conclusion having been aided by the prevailing dry season conditions.

Many introductions, particularly those of species of *Aedes* (*Stegomyia*), must have been brought about in similar fashion by the loading of drinking water already containing larvae aboard ships and canoes. A detailed study of the watering places used by sailing ships in the Pacific during the nineteenth century might shed light on the invasion routes followed by some of the mosquitoes now widespread throughout the region. Rannie (1912) illustrated "a favourite watering-place for ships" at Aneityum. The creek concerned closely resembled that seen in Fig. 60, and would undoubtedly have had marginal breeding of *Anopheles farauti* (which would be most unlikely, however, to be able to maintain itself on shipboard in water casks) and in its upper reaches would probably have supported *Culex annulirostris* as well.

A variant of this kind of situation was described by Pratt et al. (1946), who gave a formidable list of species intercepted at San Francisco and Los Angeles aboard vessels loaded with tyres from war areas. The crew of a ship returning from the New Guinea area had complained of being bitten by mosquitoes for five or six days after leaving port. A search of the cargo after arrival in California disclosed that about half of the 8,880 tyres aboard held water varying in amount from a cupful to five gallons. A large percentage of these held living larvae, the average tyre supporting from 20 to 30. *Aedes s. scutellaris* (= *A. s. hebridus*) and *Armigera milnei* Lec were present in the majority of the infested tyres. *Culex fragilis* Ludlow (= *C. papuensis* Taylor) and a *Tripterooides* near *T. quasimotata* (Taylor) were also present in the living state, two larvae and one dead adult of *Toxorhynchites* sp. were collected, and a single dead adult female of *Culex annulirostris* was recovered. Eleven further shipments of tyres were inspected. Eight of these included tyres containing water, and mosquito breeding was proceeding in three shipments. These originated from Indonesia, Calcutta and the Philippines, the mosquitoes identified being *Aedes s. scutellaris*, *A. albopictus* Skuse, *Armigera milnei* and *Culex fragilis*.

Some introductions are no doubt ascribable to mosquitoes flying aboard ships and finding suitable places to oviposit there. Thus *Culex annulirostris* could avail itself of rain water trapped in tarpaulins, lifeboats and other places, while such a species as *C. sitiens* might utilise the salt or brackish water in fire buckets on deck. In still other cases adult mosquitoes come aboard vessels offering no suitable larval habitats, and themselves survive the voyage. On the occasion of the visit to Rennell and Bellona in 1953, which was made in the Western Pacific High Commission's small motor vessel "Bina," my wife and I went aboard at 10 p.m. on August 13. The vessel was then tied up alongside the jetty at Point Cruz, Honiara,

Guadalcanal. *Culex annulirostris* was biting freely on the beach, and numbers of these mosquitoes were attracted onto the "Bina". Three were captured in the act of biting while at sea on the following evening, and another, engorged and sluggish, flew out from amongst clothing hanging on the cabin wall while we were preparing to go ashore at Bellona on the morning of August 15. The need for larval habitats does not arise either on short inter-island voyages of this sort or in trans-oceanic air journeys.

The records of the spread of several mosquitoes to new localities in recent years are of particular significance. *Culex annulirostris* was not known east of Samoa and *Culex sitiens* was understood to reach its easterly limit in Fiji a little over a quarter of a century ago when Buxton and Hopkins were working in the Pacific. Even allowing for the possibility that one or both of these species had been overlooked in the more easterly islands up to that time, the evidence is strongly in favour of *C. annulirostris* having become established in the Southern Cook Island during the decade 1925-1935 (Laird, 1953b). Within the last 15 years three species which, like *Anopheles farauti*, are not container breeders, have been reported from new localities in places where the mosquito fauna is sufficiently well known to eliminate the possibility of their having been overlooked previously. These—*Aedes vigilax*, *Aidomyia caasticta* and *Culex bitaeniorhynchus*—must have been introduced in the adult state. It is thus justifiable to conclude that with the continuing development of faster transport facilities and new commercial routes the chances of adult mosquitoes availing themselves of, and surviving, inter-island voyages are steadily increasing.

The beneficial genus *Toxorhynchites* (= *Megarhinus*) is notable for the non-biting habits of its imagines and the predacity of its large and powerful larvae. No representatives of the genus are indigenous to any of the Pacific islands east of New Britain, where *T. inornatus* (Walker) occurs. The larval habitat preferences of *Toxorhynchites* being similar to those of species of *Aedes* (*Stegomyia*), attempts have been made to establish the former mosquitoes in the Pacific as a control measure against members of the *scutellaris* complex. *T. inornatus* was introduced into Hawaii from New Britain in 1929 (Swezey, 1930) as an enemy of *A. (Stegomyia) albopictus* (Skuse), but the colony soon died out (Swezey, 1931). The same species was introduced into Fiji in 1933 (Paine, 1934) with the same lack of success. However, the Javanese *T. splendens* (Wiedemann) has now gained a foothold in various parts of the Fiji Group (Paine, 1943). *T. brevipalpis* (Theobald) has more recently been brought to Hawaii from South Africa (Bonnet and Hu, 1951), but it is not known whether this species has become firmly established as yet. Most of the larvae gathered together in South Africa for this introduction attempt were collected from leaf axils (Bonnet and Hu, 1951). As *A. albopictus* is primarily a simple container breeder it is suggested that more satisfactory results might attend the introduction into Hawaii of one of the Malayan species of *Toxorhynchites* known to prey upon this *Stegomyia* in nature, rather than a species which breeds to a large extent in leaf axils.

The only predators recorded from container habitats were two leaf axil breeders on Guadalcanal, *Corethrella* sp. and *Tripterooides malhesoni*. Larvae of the latter mosquito are cannibalistic and also prey upon *Uranotaenia quadrimaculata* (Belkin, 1950; Laird, 1955).

As is well known, members of the subgenus *Lutzia* of *Culex* are predaceous in the larval state. *C. halifaxi* was collected from 12 larval habitats in the Solomons and Queensland. Single fourth instar larvae of this species have been shown to destroy an average of five other larvae per day under laboratory conditions in New Britain, exhibiting a decided preference for those of *An. farauti* over those of *C. pullus* (4: 1) (Laird, 1947). The species is usually found in transient pools, containers or recently ponded streams. Habitats within these categories tend to contain more numerous mosquito larvae than do ponds of long standing and in all 12 cases larvae of other species were present and were usually common or abundant

despite the presence of *C. halifaxi*. While this mosquito certainly helps to check the breeding of other species its usefulness is limited by its cannibalistic habits (Laird, 1947). Nevertheless, it must be reckoned among the few biological control factors operating against mosquito breeding in transient pools in the region under consideration.

Although *C. halifaxi* seldom bites man, the fact that it does bite at all renders it inadvisable to consider introducing the species to new territories as a biological control agent. The same applies to the Australasian species of *Aedes* (*Micidus*) and to such mosquitoes as the African *Eretmapodites* spp. which unfortunately offset their very active predacity as larvae by the fierce biting habits of the adults (Haddow, 1946).

Members of the subfamily Corethrinae of the Culicidae are predaceous as larvae but the short mouthparts of the adults are not formed for biting (Edwards, 1932). No surface water corethrinae occur in the South Pacific, and the introduction of suitable species to fill an as-yet un-utilized ecological niche is worthy of serious consideration. *Eucorethra underwoodi* Underwood is sufficiently abundant in Quebec to be considered of importance in reducing *Aedes* populations in woodland pools (Jenkins and Knight, 1950), and while it is hardly to be expected that this species would become adapted to tropical conditions, worthwhile results might be expected to follow introductions of such tropical corethrinae utilizing surface water larval habitats as *Corethrella incpta* Annandale from Ceylon or the several such species of *Chaoborus* (*Sayomyia* and *Neochaoborus*) listed by Edwards (1932).

DIPTERA other than CULICIDAE. Other members of the suborder Nematocera collected from aquatic habitats included representatives of the families Tipulidae, Psychodidae, Tendipedidae (= Chironomidae) and Heleidae (= Ceratopogonidae).

Tipulid larvae were only recognized on five occasions, at Bellona, Sikaiana and Funafuti and in Viti Levu. Two of the collections were from leaf axils (Bellona and Sikaiana), two from pools (Sikaiana and Funafuti) and one from a flowing stream (Viti Levu). The family Tipulidae is quite well represented in the tropical Pacific. Most of their larvae are probably to be found in damp places rather than in standing water, while a more intensive search of streams might reveal a wider range of species.

Larval psychodids were present in six collections, all from leaf axils or small containers. *Psychoda* was recorded from Tutuba, Viti Levu and Funafuti, and *Telmatoscopus* was found on Aneityum and Viti Levu. Dr. G. H. Satchell made these determinations, informing me that while none of the larvae could be referred to any known species each of the collections of *Psychoda* is specifically distinct from the others while all the examples of *Telmatoscopus* belong to the same species. The dissection of a mature pupa present with one of the batches of larvae of the last-named genus indicated that the species is not the Fijian *T. viensis* Satchell and is undescribed. Satchell (p.c., 1954) collected larvae of his *T. viensis* from a tree hole in which were larvae of *Aedes pseudoscutellaris*. The pan-tropical *Telmatoscopus albipunctatus* Williston was not collected from larval habitats, but adults of this species, which breeds in drains, containers and even small ground pools in Hawaii (Williams, 1943), were common in a shower room at Luganville, Espiritu Santo, on July 18, 1953.

The developmental stages of chironomids (Tendipedidae) were very commonly collected from all kinds of larval habitats. The genus *Tendipes* (= *Chironomus*) was recorded from Queensland to Fiji, in Samoa and at Tarawa. Several species were involved, but determinations beyond the generic level could not be made in the absence of adults. The apparent absence of this genus and for that matter of the family itself from aquatic habitats at Aitutaki and Funafuti is of interest in view of the abundance of chironomids elsewhere and of the fact that numerous collections were made at both atolls. Larvae and pupae of *Pentaneura* (= *Tanypterus*)

TABLE XIII  
OCCURRENCE AND DISTRIBUTION OF DIPTERA OTHER THAN CULICIDAE  
LOCALITY

SYSTEMATIC POSITION AND COLLECTION NUMBER	NO. OF TAXA COL- LECTED	LOCALITY					
		TIME	QUEENSLAND	SOLOMON IS.	NEW C.-LECLERCQ IS.	NEW HEBRIDES	FIJI
NIMATOGRA	3		x				
TRIPODIDE	1			x			
Undetermined Tipulidae 39 <sup>1</sup> , 287, 288, 39 <sup>1</sup> , 80 <sup>1</sup>							x
PSYCHODIDAE	5					x	
<i>Psychoda</i> spp. 25, 35 <sup>1</sup> , 64 <sup>1</sup> . . . . .	4			x			
<i>Telmatoscopus</i> sp. 99, 316, 74 <sup>1</sup>							
TENDIPIDIDAE	5		x	x	x		
<i>Tendipes</i> spp. 2 <sup>1</sup> , 29, 30, 17, 13, 47, 19, 64, 66, 17 <sup>1</sup> , 91, 18 <sup>1</sup> , 110, 30 <sup>1</sup> , 182, 187, 190, 32 <sup>1</sup> , 220, 221, 228, 230, 231, 232, 41 <sup>1</sup> , 238, 242, 249, 250, 252, 255, 263, 267, 273, 274, 276, 278, 279, 280, 302, 306, 310, 359, 366, 371	2	x					
POLYPEDILUM spp. 169, 339							
<i>Pentaneura</i> spp. 3, 37, 71, 261, 264, 317, 72 <sup>1</sup> , 76 <sup>1</sup> , 336, 339, 369	12		x	x	x		
Undetermined Hydrobaeninae 316, 79 <sup>1</sup> , 363							
<i>Colocasia</i> sp. 269			x	x	x	x	x
IIIIDAE	3	x		x	x	x	
<i>Forcipomyia</i> sp. 316, 69 <sup>1</sup> , 319, 74 <sup>1</sup> , 76 <sup>1</sup>							
<i>Dasyhelea</i> sp. 83, 86, 88, 93							
<i>Forcipomyia</i> ( <i>Apelma</i> ) aff. <i>comis</i> Johannsen 37, 12 <sup>1</sup> , 19 <sup>1</sup> , 214, 223 . . . . .	16	x	x	x	x		
<i>Culicoides</i> sp. 331, 340							
BRACHYCERDA							
ORTHOPTERA	5	x		x			x
SPRATTINIIDAE							
Undetermined Sciaridae 6, 43, 15, 64, 66, 91, 101, 23, 143, 146, 302, 321	3		x	x			x
CYLOCOPTERA				x	x		
SYRPHIDAE							
Undetermined Syrphidae 5, 25 <sup>1</sup> , 251, 64 <sup>1</sup> , 189, 316, 318, 324							
<i>Eristalis tenax</i> L. 172, 292, 362							
MUSCOPHAGA							
Undetermined Muscidae 2 <sup>1</sup> , 19, 23, 12 <sup>1</sup> , 99, 100, 26 <sup>1</sup> , 39, 161, 177, 179, 232, 244, 286, 287, 63 <sup>1</sup> . . . . .	45	x	x	x	x	x	x

were collected in Queensland, the Solomons, the New Hebrides and Fiji. This genus was much more commonly found in surface water than in container habitats, while a little over half of the *Tendipes* records were from containers. Representatives of the genus *Polypedilum* were collected in Samoa, this being the only record of chironomids other than *Tendipes* east of Fiji.

Heleoids figured in a number of collections, but were not found east of Fiji. An undescribed species of *Forcipomyia* was found in the leaf axils of *Colocasia*, *Freynechia* and *Cordyline* in Viti Levu, one collection also being made from a transient forest pool. All the other heleoids dealt with were restricted to container habitats with the exception of *Culicoides* sp. from Queensland. An undescribed species of *Dasyhelea* was found in tree holes, a rock hole and an old canoe at Futuna, while a species of *Forcipomyia* closely comparable with *F. (Apelma) comis* Johannsen was taken from leaf axils of *Colocasia*, *Alocasia*, and *Pandanus* at Art (Belep Islands), Aneityum, Espiritu Santo and Guadalcanal. The immature stages

of *F. comis* were first described from taro axils in Indonesia by Mayer, according to Dr. W. Wirth (p.c., 1951). It is considered that the dispersal of this species might well have been brought about through human agency.

Relatively little is known of the distribution of the above groups of Nematoecra in the Pacific. The comparatively few records considered herein suggest a diminishing representation of genera in an eastward direction. As to the impact of these insects upon mosquitoes, *Pentaneura* has predatory larvae, and Howard et al. (1912) stated that larval *P.* (== *Tanypus*) *dyari* were active in destroying mosquito larvae in breeding jars. None of the examples collected in the Pacific were observed to attack mosquitoes, and the latter were often common or abundant in habitats containing these midges. Lamborn (1923) referred to the belief that anopheline larvae are usually absent from chironomid larval habitats, and suggested that this might be due to food competition, the midges collecting up a high percentage of the available algae for the purpose of forming their larval cases. The presence of chironomids was certainly no bar to anopheline breeding in the habitats studied in the Pacific, and mosquitoes were more often than not abundant in pools in which midge larvae were present. Two case were noted, though, in which *Tendipes* larvae were present in myriads and might perhaps have inhibited mosquito breeding. In the first of these the pool concerned was a transient one (Futuna, coll. no. 17<sup>1</sup>). Its muddy bottom was quite covered by a wriggling mass of chironomid larvae and pupae, and no mosquitoes were present although the pool appeared eminently suited to the requirements of *Aedes vexans nocturnus*. The other habitat, a semi-permanent pond in a taro pit dug through the water table at Tarawa (coll. no. 310), held only a few rare larvae of *A. vexans nocturnus*. Once again the muddy bottom was quite covered by the developmental stages of *Tendipes* sp., and adults were constantly emerging at the surface. More imagines were resting on the marginal and emergent vegetation (*Mariseus peninsulae*), which was swarming with ants (identified by Mr. Nixon of the Commonwealth Institute of Entomology as *Phaidole* sp.) busily engaged in capturing and bearing away the still-helpless midges. One of the midges was captured in flight above the pond with an ant still clinging to it. The larvae of the *Tendipes* concerned in these two instances were typical bloodworms which feed on whatever diatoms, algae and other organic debris fall to the bottom (Leathers, 1923). It is probable that the competition for the available food was such as to all but preclude bottom-browsing mosquito larvae from obtaining adequate nourishment. The Futuna pool was entirely lacking in predators, while a few dragonfly nymphs were the only natural enemies to be contended with by the Tarawa midges. Conditions thus could hardly have been more favourable for the development of such great numbers of individuals.

Undetermined soldier fly larvae (Stratiomyidae; suborder Brachycera, section Olfithorhaphia) were collected from 12 ground pools in Aneityum, Uvea, New Caledonia and Viti Levu (Table XIII). These sluggish larvae were particularly abundant in New Caledonia and Uvea, where seven of the collections were made. They were found only in semi-permanent and permanent ground pools, and thrived in rather polluted or brackish water. Séguy (1950) and Lambert (1930) both referred to the common occurrence of stratiomyiid larvae in European brackish marshes.

Hover fly larvae (Syrphidae; suborder Brachycera, section Cyclorrhapha) were found on 11 occasions, the most easterly record being from Funafuti. Eight of the collections were from containers, especially coconut husks containing decomposing copra and leaf axils in which the water was polluted by decomposing vegetation. The remaining three habitats were ground pools subject to pollution by animals, in Queensland, Tonga and Samoa. In these last three instances the species concerned was identified as *Hisatidis tenax*. This cosmopolitan syrphid appeared in New Zealand towards the end of the nineteenth century, Smith (1890) thinking it probable that the introduction had been effected by way of the mail steamers

which at that time sailed each month from San Francisco to Auckland, and making the prophetic statement that "possibly we may soon have records of the occurrence of *E. tenax* in other islands of the Pacific."

Finally, larval cyclorrhaphids—most of them probably referable to the Muscidae—were found on various occasions (Table XIII). Fouling was usually in evidence in the breeding places concerned, a favourite habitat being coconut husks containing decomposing copra.

**COLEOPTERA.** Water beetles figured in the collections from all the islands adequately surveyed with the exception of Bellona, Aitutaki, Tarawa, Funafuti and Niukunono. At Funafuti a small beetle was found to be abundant in the decomposing copra in a coconut husk (coll. no. 64<sup>1</sup>). This proved to be *Hyptonicus ocularis* Fairmaire, not really a water beetle but a member of the family Nitidulidae which is frequently associated with decaying vegetable matter.

TABLE XIV  
OCCURRENCE AND DISTRIBUTION OF COLEOPTERA  
LOCALITY

SYSTEMATIC POSITION AND COLLECTION NUMBER	NO. OF TIMES COLLECTED	LOCALITY								
		Queensland	Solomon Is.	New Caledonia	New Hebrides	Fiji	Tonga	Cook Is.	Gilbert Is.	Fiji Is.
<b>COLEOPTERA</b>										
<i>Hydatophylax consanguineus</i> Aubé Dytiscidae 38, 10 <sup>1</sup> , 13, 45, 48, 15 <sup>1</sup> , 146, 171, 176, 291, 299, 328, 315, 365, 370, 371	16	x	x	x	x	x				
<i>Rantus annectens</i> (Sharp) Dytiscidae 16 <sup>1</sup> , 291, 320	3		x	x	x					
<i>Bidewellus</i> spp. Dytiscidae 72, 271, 291, 292, 327, 33 <sup>1</sup> , 367	7	x	x	x	x					
<i>Bidewellus fijiensis</i> Balfour-Browne Dytiscidae 1 <sup>1</sup> , 52 <sup>1</sup>	2				x					
<i>Copelatus fijiensis</i> Zimmerman Dytiscidae 48 <sup>1</sup>	1				x					
<i>Copelatus strigosulus</i> (Fairmaire) Dytiscidae 48 <sup>1</sup>	1				x					
<i>Helochares</i> sp. Hydrophilidae 302	1				x					
<i>Limnoderessus aff. levereri</i> Balfour-Browne Dytiscidae 6	1				x					
<i>Enochus exsuriens</i> (Walker) Hydrophilidae 17, 38, 285	3	x	x	x						
Undetermined larval Helodidae 9, 31 <sup>1</sup> , 222, 67 <sup>1</sup> , 68 <sup>1</sup> , 70 <sup>1</sup>	6	x	x	x						
<i>Copelatus</i> spp. Dytiscidae 33 <sup>1</sup> , 38 <sup>1</sup> , 48 <sup>1</sup> , 52 <sup>1</sup> , 77 <sup>1</sup>	5	x	x	x						
<i>Cybister tripunctatus</i> Castelnau subsp. Dytiscidae 18, 321, 330, 349, 359	5	x		x	x					
<i>Dinutulus australis</i> (Fabricius) subsp. Gyrinidae 1 <sup>1</sup> , 48, 50 <sup>1</sup> , 52 <sup>1</sup> , 326, 327, 330, 334, 349, 84 <sup>1</sup> , 365	11	x	x	x						
<i>Copelatus cheesmanae</i> Balfour-Browne Dytiscidae 28, 76, 96, 98	1		x							
<i>Hyphodruss elegans</i> Montrouzier Dytiscidae 6, 10 <sup>1</sup>	2		x							
<i>Platynectes insularis</i> Balfour-Browne Dytiscidae 36, 76, 16 <sup>1</sup>	3		x							
<i>Copelatus gentilis</i> Sharp Dytiscidae 12, 22, 45 <sup>1</sup>	3	x	x							
<i>Guignotus</i> spp. Dytiscidae 31, 41, 42, 95, 143, 195, 261, 268, 331, 333, 340, 341	12	x	x	x	x					
<i>Limbodessus compactus</i> (Clark) Dytiscidae 48, 71, 91, 95, 16 <sup>1</sup> , 250, 336, 352, 371	9	x	x	x	x					
<i>Enochus</i> spp. Hydrophilidae 41, 42, 46, 104, 363	5	x	x	x	x					
<i>Laccophilus clarkei</i> Sharp Dytiscidae 9, 10, 18, 57, 65, 15 <sup>1</sup> , 326, 330, 336, 350, 352, 354, 363, 365, 368, 370, 371	17	x	x	x	x					

SYSTEMATIC POSITION AND COLLECTION NUMBER	LOCALITY								
		No. or LINES COL- LECTED	Queensland	Solomon Is.	New Caledonia	New Hebrides	Fiji	Tonga	Sarawak
<i>Sternolophus rufipes</i> Fabricius Hydrophilidae 22, 27, 13, 341, 363		5	x	x	x				
<i>Bidessus checmamea</i> Balfour-Browne Dytiscidae 47, 52, 53, 61		4		x					
<i>Hyalicrus bimaculatus gorii</i> Aubé Dytiscidae 140, 23		2		x					
<i>Hydrovatus fasciatus</i> Sharp Dytiscidae 65		1		x					
<i>Paracymus pygmaeus</i> (MacLeay) Hydrophilidae 142		1		x					
<i>Carishydrus serialis</i> Faunel Dytiscidae 138, 250		2	x	x					
<i>Dineutus bougainvillensis longipeni</i> Ochs Gyrinidae 32, 209, 311, 361, 372		5		x					
<i>Laccobius (Notoberous)</i> sp. Hydrophilidae 227		1		x					
<i>Sternolophus marginicollis</i> Hope Hydrophilidae 42 <sup>a</sup>		1		x					
<i>Berous pulchellus</i> , MacLeay Hydrophilidae 199, 271, 371, 372		4	x	x					
<i>Platynectes</i> 18-maculatus MacLeay subsp. Dytiscidae 31 <sup>a</sup> , 209, 210, 32 <sup>a</sup> , 37 <sup>a</sup> , 328, 319, 363		8	x	x					
<i>Antiporus</i> sp. Dytiscidae 364			1	x					
<i>Berous</i> sp. Hydrophilidae 83 <sup>a</sup>			1	x					
<i>Bidessus ambobili</i> Sharp Dytiscidae 351			1	x					
<i>Bidessus</i> aff. <i>denticulatus</i> Sharp Dytiscidae 361			1	x					
<i>Chostoneutes sharpi</i> Sharp Dytiscidae 353, 357			2	x					
<i>Clypeodixus migrator</i> Sharp Dytiscidae 352, 353			2	x					
<i>Copeiatus clarki</i> Sharp Dytiscidae 334, 369			2	x					
<i>Copeiatus irregularis</i> MacLeay Dytiscidae 328, 346, 318, 355, 357, 369		6	x						
<i>Copeiatus nigrolineatus</i> Sharp Dytiscidae 369, 371		2	x						
<i>Dineutus neohollandicus</i> Ochs Gyrinidae 82 <sup>a</sup> , 367		2	x						
<i>Globaria punctata</i> Blackburn Hydrophilidae 358		1	x						
<i>Guignotus basalis</i> MacLeay Dytiscidae 371		1	x						
<i>Guignotus daemeli</i> Sharp Dytiscidae 358, 370, 371, 372		4	x						
<i>Guignotus godeffroyi</i> Sharp Dytiscidae 329, 357, 369, 371		4	x						
<i>Guignotus signatus</i> Sharp Dytiscidae 333		1	x						
<i>Hydraena</i> sp. Hydrcnidae 346		1	x						
<i>Hyphydrus</i> aff. <i>elegans</i> Montreux Dytiscidae 336		1	x						
<i>Hyphydrus lyraeus</i> Swart. Dytiscidae 334		1	x						
<i>Hyphydrus</i> 10 maculatus Wehn. Dytiscidae 363		1	x						
<i>Laccophilus cingulatus</i> Sharp Dytiscidae 333, 354, 368, 369		4	x						
<i>Laccophilus religiosus</i> Sharp Dytiscidae 369, 371		2	x						
<i>Laccophilus unifasciatus</i> Sharp Dytiscidae 353, 358		2	x						
<i>Macrogyrus australis</i> Brillé Gyrinidae 328, 334, 335, 82 <sup>a</sup> , 345, 363, 370		7	x						
<i>Paracymus</i> aff. <i>sublineatus</i> Blackburn Hydrophilidae 346		1	x						
<i>Regimbartia attenuata</i> Fabricius Hydrophilidae 364, 368		2	x						

At least 16 known species and 20 undescribed ones (Dytiscidae, Gyrinidae and Palpicornia) were identified by Dr. J. Balfour-Browne. The undescribed species have been lumped together under the relevant generic names in Table XIV without regard to the number of species concerned.

As Table XIV indicates, the strong-swimming Dytiscidae are the dominant water beetles of the South Pacific. The habitat occurrence of these insects is of some interest in the light of the demonstration by Needham and Williamson (1907) that, in general, the size of water beetles is graded according to the distance of their operational zone from the shore, the larger species occurring further out into the water than the smaller ones. A similar generalization appears to be applicable to the size of habitats themselves. Thus the largest dytiscid collected, *Cybium tripunctatum* subsp., was found on five occasions, always in extensive ponds (categories 1 and 4). Medium-sized dytiscids of the genera *Hydaticus*, *Laccophilus* and *Limnoderus* figured in 51 species/records, 38 (75 per cent.) of which were referable to category 1 and 2 habitats, while only 22 (45 per cent.) of the 49 species/records for small beetles (*Bidesus*, *Guignotus*, *Copelatus*) were from these habitats and eight (16 per cent.) were from simple containers (category 6). No dytiscids were collected east of Samoa, and in fact the only members of the family known from eastern Polynesia are *Bidesus skottbergi* Zimmeiman from Easter Island and *Rantus debilis* (Sharp) from Tahiti (Balfour-Browne, 1945). Whirligig beetles (Gyrinidae) were found in Queensland, Guadaluana, Ari (Belep Islands) and Viti Levu. No species of this family occur east of Fiji. Only a third as many representatives of the Palpicornia as Dytiscidae were collected, the most easterly records being from Fiji (Table XIV). These insects, many of which are terrestrial or only semi-aquatic, are known to occur quite widely in the eastern Pacific. They are found as far east as Mangareva (Tuamotu Group) and seven species have been listed from Samoa and one each from the Cook Islands, the Gilberts and the Tokelau Group (Balfour-Browne, 1945).

It is not proposed to discuss the distribution of the Pacific water beetles in detail herein, for any amplification of Balfour-Browne's earlier analysis of this fauna would lean heavily on the numerous new species collected which have yet to be described. On the basis of the collections then before him that author (1945) pointed out that, discounting the Solomons and New Hebrides the water beetle faunas of which are probably much richer than the available evidence suggests, the number of species declines with increasing distance from Australia, while the percentage endemicities of the Dytiscidae increase enormously from Queensland to tropical Polynesia, those of the Gyrinidae do likewise from Queensland to Fiji, and those of the Palpicornia remain about the same in all the areas concerned. He suggested that the lower endemicity within the latter group may perhaps be due to the fact that the small palpicons, not being strong swimmers and spending much of their time in aquatic vegetation, avail themselves more readily of human transportation than do the Dytiscidae and Gyrinidae. Balfour-Browne concluded that the water beetle fauna of Fiji is Melanesian rather than Polynesian, forming a well-defined faunistic group of the Melanesian subregion of Australasia.

Hinman (1934) referred to numerous reports of the efficiency of water beetles as mosquito larval predators. While acknowledging their voracity, particularly that of the Dytiscidae, in small aquaria, he pointed out that it is common to find water beetles associated with heavy mosquito populations in nature and expressed doubts as to whether any preference is exhibited for culicid larvae over other food organisms. Simple experiments carried out in New Britain (Laird, 1947) indicated that adults of *Hydaticus litigiosus* Régimbart destroy about thirty times more larvae of *Culex pullus* than of *Anopheles farauti* when supplied with either pure or mixed cultures of these mosquitoes, the head-downwards position assumed by this medium-sized dytiscid when at or near the water surface largely determining its source of prey. A small dytiscid of the genus *Copelatus*, which sought its food near the surface,

destroyed equivalent numbers of anopheline and culicine larvae, while the little gyrinid *Gyrinus sericeolimbatus* Régnier readily devoured larvae of *Anopheles punctulatus* in transient pools in which there was no floatage.

It is quite certain that water beetles do not of themselves do more than partially check mosquito breeding in surface water habitats. Frohne (1953) stated that the Alaskan *Culiceta impatiens* (Walker) may constitute the principal animal production of ponds despite the presence of abundant and patently voracious dytiscid and gyrinid larvae. Although observation in the laboratory at Suva indicated that *Hydaticus consanguineus* attacks culicine larvae as readily as does its relative in New Britain, only two of the 16 ponds from which this species was recorded altogether lacked developmental mosquitoes, while but one of the 17 ponds from which the equally voracious *Laccophilus clarki* was collected was without larvae (Table XIV). In Queensland two species of *Culex* were abundant and one of *Anopheles* was common in a backwater (coll. no. 369) supporting abundant dytiscids of seven species, while anopheline larvae were common in another habitat (coll. no. 371) from which eight species of the Dytiscidae and a hydrophilid were recorded.

Larvae in container habitats are, however, likely to suffer the same fate as those in laboratory aquaria when dytiscids are present in any numbers. Seven collections of these beetles were made from containers, species of *Copelatus* being present in six instances and *Platynectes insularis* in the remaining one. Mosquitoes were altogether absent from three of these habitats (coll. nos. 38<sup>1</sup>, 45<sup>1</sup>, 48<sup>1</sup>), larvae were very rare in two (coll. nos. 36, 96), the powerful larvae of *Culex halszki* were quite common in one (coll. no. 346), while culicid breeding could be classified as abundant in but a single instance (coll. no. 98).

TABLE XV  
OCCURRENCE AND DISTRIBUTION OF ARACHNIDA

SYSTEMATIC POSITION AND COLLECTION NUMBER	NO. OF TINNS. COLLECTED	LOCALITY	No. of TINNS. COLLECTED									
			Queensland	Solomon Is.	New Caledonia	New Hebrides	Iiji	Tonga	Samoa	Cook Is.	Gilbert Is.	Dilice Is.
<b>ARACHNIDA</b>												
<b>ARANIDA</b>												
Undetermined Argiopidae 50 <sup>1</sup> , 52 <sup>1</sup> , 303	3			x			x			x		
<i>Dolomedes fuscus</i> L. Koch Pisauridae 298	1			x			x					
<i>Leucouge</i> sp. Argiopidae 79 <sup>1</sup>	1			x			x					
<i>Tetragnatha mandibulata</i> Walckenaer Argiopidae 298	1			x			x					
<i>Tetragratha</i> sp. Argiopidae 1 <sup>1</sup> , 46 <sup>1</sup>	2			x			x					
<i>Dolomedes</i> spp. Pisauridae 39, 10 <sup>1</sup> , 11 <sup>1</sup> , 46, 72, 23 <sup>1</sup> , 31 <sup>1</sup> , 250, 302, 303, 321, 336	12	x	x	x	x	x						
<i>Araneus thesi</i> Walckenaer Argiopidae 335	1	x										
<i>Lycosa</i> sp. Lycosidae 326	1	x										
<b>HYDARAGARINA</b>												
Undetermined Hydracarina 10 <sup>1</sup> , 19 <sup>1</sup> , 269, 306	4	x	x	x	x	x	x					
<i>Neunmania</i> spp. Pionidae 95, 250	2	x	x	x	x	x						
<i>Arrenorurus</i> spp. Arrenuridae 88, 330	2	x		x	x	x						
<i>Eylais</i> sp. Elyaidae 371, 372	2	x										
<i>Hydrachna</i> sp. Hydrachnidae 349	1	x										
<i>Limnesia</i> spp. Sperchoniidae 355, 360	2	x										

**ARANEIDA.** Horizontal webs of spiders of the family Argiopidae, which is abundantly represented throughout the South Pacific (Berland, 1934)—had been spun just above the surface of eight of the water bodies studied (Table XV). Mosquito larvae were present in only three of these habitats, but their absence from four

of the others was explicable without the spiders being taken into consideration. In the case of one rock pool, though (coll. no. 79<sup>1</sup>, Viti Levu), the webs of a multitude of argiopids of the genus *Leucauge* so effectively screened off all approaches that it would have been well nigh impossible either for imagines to reach the surface to oviposit or for emerging mosquitoes to make good their escape. The webs over the three pools in which larvae were present had all ensnared a number of mosquitoes. Similar observations have frequently been made elsewhere (Wesenberg-Lund, 1920-21; Hinman, 1934a; Laird, 1917).

Hunting spiders are not infrequently seen scurrying over the surface of pools. Undetermined species of *Dolomedes* having such habits were recorded on 12 occasions in New Caledonia, the New Hebrides, the Solomons and Fiji, while a species of *Ixrota* was collected from the water film of a Queensland pond (Table XV). Representatives of both these genera are known from as far east as the Society Islands (Berland, 1931). Bishop and Hart (1931) recorded that a North American lycosid readily captures mosquito larvae and pupae at the water surface.

Spiders exhibit the usual decrease in representation from west to east across the Pacific. Thus, while the widespread *Dolomedes fasciatus* is the only member of the family Pisauridae known from Samoa and Fiji, and a single species of the genus, *D. roukahiwa* Walckenaer, is native to the Marquesas, five species of pisaurids occur in New Caledonia (Berland, 1934). The distribution of the Argiopidae is presumably more favoured by winds than is that of the Pisauridae, and Berland (1931) was able to list 10 species from New Caledonia, 22 from Samoa and six from the Marquesas. No strictly aquatic spider such as the European *Agyrtoma aquatica* (L.) has been recorded from the tropical Pacific.

**HYDROCARINA.** An undetermined water mite was observed as far east as Tarawa, while six collections including representatives of four genera were made in Queensland. A species of *Neuanaria* was taken from Lake Tengano, Rennell, and two genera were recorded from the New Hebrides (Table XV). Little is known of the distribution of the group in the islands east of Australia, but the meagre records listed herein suggest that it is not well represented. Ectoparasitic mites were not found on any of the mosquitoes studied, but the examples of *Hydryllina* sp. from Queensland (coll. no. 349) were in the advanced nymphophan stage and were attached to the ventral surface of the abdomen of the large dytiscid beetle *Cybister trispinosus*. No observations were made as to the feeding habits of any of these water mites. In New Britain *Limnesia jamurensis* Oudemans attacks the eggs and very small larvae of anophelines and culicines (Laird, 1917) and similar behaviour has been noted in Canada (Hearle, 1926).

**MOLLUSCA.** The tropical Polynesian islands are characterized by a complete absence of freshwater bivalves and a notable scarcity of pulmonates. Operculates of the genera *Melania*, *Neritina* and *Naticella* are widespread (Cooke, 1913).

Freshwater molluscs are lacking from Bellona and Nukunono in the absence of suitable habitats. Their apparent absence from Tarawa contrasted sharply with the relative abundance of *Melania maggi* at Funafuti, both atolls having numerous ponds of similar type in taro pits. These animals were found in all the other isolated islands visited, representatives of *Melania* and *Fluviopupa* even occurring in one of the few small streams on the little island of Futuna.

*Melania*, the dominant operculate genus of South Pacific ponds and streams, figured in 20 (33 per cent.) of the 38 collections featuring aquatic snails made from the Solomons to Funafuti. Although this was the only genus noted east of Samoa (Table XVI), *Neritina* and *Naticella*, as well as *Melania*, are known from as far east as the Marquesas (Adamson, 1935.). The two former genera were each collected once only, in Samoa (coll. no. 171) and Guadaluana (coll. no. 43<sup>1</sup>) respectively. *Fluviopupa* also occurs well to the east, being known from the Tubuai Group (R. K. Dell, p.c., 1953). The pulmonate family Bulimidae occurs as far east as the Tuamotu Group, where it is represented by *Isidora moderata* Glessin

TABLE XVI  
OCCURRENCE AND DISTRIBUTION OF MOLUSCA

SYSTEMATIC POSITION AND COLLECTION NUMBER	NO. OF TOMLS COL. LECTED	LOCALITY						
		Queensland	Solomon Is.	New Caledonia	New Hebrides	Fiji	Tonga	Samoa
<b>MOLUSCA</b>								
<i>Melania magenii</i> Gassies Thiaridae 58 <sup>1</sup> , 311, 65 <sup>1</sup> , 66 <sup>1</sup>	4						x	
<i>Omphalotropis zebraiolata</i> Mousson (land snail, adventitious) 66 <sup>1</sup>	1						x	
<i>Melania baldimii</i> Aney Thiaridae 116, 118, 122	3						x	
<i>Melanoides samonae</i> (Reeve) Thiaridae 29 <sup>1</sup> , 171	2						x	
<i>Neritina chrysocolla</i> (Gould) Neritidae 171	1						x	
<i>Open operum</i> Pfeiffer (land snail, adventitious) 15 <sup>1</sup>	1						x	
<i>Planorbis</i> spp. <i>sensu lato</i> Planorbidae 29 <sup>1</sup> , 250	2	x					x	
<i>Physastra</i> spp. <i>sensu lato</i> Bulinidae 6, 9, 16 <sup>1</sup> , 101, 46 <sup>1</sup>	5	x	x					
<i>Physastra</i> (?) <i>singuata</i> Gould Bulinidae 11 <sup>1</sup> , 302, 321, 77 <sup>1</sup>	4		x					
<i>Melania</i> aff. <i>seifio</i> (Gould) Thiaridae 50 <sup>1</sup>	1		x					
<i>Subulina octona</i> Brugière (land snail, adventitious) 149	1		x					
<i>Melania</i> spp. Thiaridae 250, 285, 303	3	x	x					
<i>Flu. isotoma brevior</i> Aney 16 <sup>1</sup>	1		x					
<i>Melania petri</i> Philippi Thiaridae 10 <sup>1</sup>	1		x					
<i>Physastra antecula</i> Gassies Bulinidae 110, 23 <sup>1</sup>	2	x						
<i>Physastra tetra</i> Morelet Bulinidae 13, 15 <sup>1</sup> , 68, 69	4	x						
<i>Planorbis rossetieri</i> Crosse Planorbidae 138, 111, 116	3	x						
Undetermined marine cerithiid mollusc 24 <sup>1</sup>	1	x						
<i>Melania sanctaecrucis</i> Quoy and Gaimard Thiaridae 43 <sup>1</sup>	1	x						
<i>Melaria reticulata</i> Hinds Thiaridae 32 <sup>1</sup> , 210, 36 <sup>1</sup> , 23 <sup>1</sup> , 26 <sup>1</sup> , 283	6	x						
<i>Naticella sauveti cularis</i> Sowerby 13 <sup>1</sup>	1	x						
<i>Glyptostoma</i> sp. Planorbidae 370	1	x						
<i>Lenameria beddoensis</i> Nelson and Taylor Bulinidae 336, 350, 351	3	x						
<i>Lerunereria</i> sp. Bulinidae 337, 358, 369	3	x						
<i>Papillinaea hawaiiensis</i> Iredale Lymnaeidae 3, 0	1	x						
<i>Steronaclana denzilensis</i> Brot Thiaridae 83	1	x						

in the taro cultivations of Mangaoreva (Seurat, 1931). We collected bulinids referable to *Physastra* in Tonga, Fiji and the New Hebrides. This family occurs abundantly in New Caledonia (Cooke, 1913), and six (60 per cent.) of the 10 relevant collections from this island and Uvea included *Physastra antecula* or *P. tetra*. The family Bulinidae is well represented in Queensland (Cooke, 1913), and members of its genus *Lenameria* featured in six (75 per cent.) of the eight Australian collections which included snails.

Endemic species of flat-coiled pond snails occur commonly in Queensland and the New Caledonian area. *Planorbis rossetieri* being frequently encountered at Uvea (Table XVI). A small species of this genus was found to be abundant at the edge of Lake Tenggano, Renrell, while another was collected from an extensive rock pool alongside two cultivations near Apia, Samoa (coll no. 29<sup>1</sup>). The latter was doubtless the same as that found in a marsh on Upola by Buxton and Hopkiss

(1927), according to whom Dr. Montague Cooke considered the species as probably recently introduced. Although there are no known indigenous species of *Planorbis* to the east of the Loyalty Islands, there is a possibility that the species from Rennell is new. On the other hand, the snails concerned were found in the immediate vicinity of taro cultivations, and despite the isolation of this island they could have been introduced with *Colocasia* plants. A single species of *Unio* was listed from the Solomon Islands by Cooke (1913). This appears to be the furthest extension of freshwater bivalves into the tropical South Pacific. No members of this group figured in any of the present collections. Four genera of freshwater snails were recorded from Queensland (Table XVI), none of these being represented in the South Pacific.

Aquatic molluscs exhibit a general preference for alkaline waters. Only 12 (25 per cent.) of our collections were from water of an acid reaction (pH 5.8 to pH 6.8), the hydrogen ion content of the other habitats concerned ranging from pH 7.0 to pH 8.4 (av., pH 7.6). Snails were sufficiently abundant to be regarded as the dominant life form present in only three habitats, flowing streams in Guadalcanal (coll. no. 36<sup>1</sup>; pH 7.2) and Viti Levu (coll. no. 50<sup>1</sup>; pH 7.0) and a ponded river in Guadalcanal (coll. no. 43<sup>1</sup>; pH 7.4). The bottom was of smoothly rounded stones in all cases, *Melania* being the only molluscan genus present in the first two habitats and the dominant genus in the last one. There was actually some degree of water movement in habitat no. 43<sup>1</sup>, as water was still trickling downstream beneath the topmost layers of dried-out stones in the river bed concerned. These observations are in keeping with our knowledge of *Melania*, the members of this genus being pre-eminently adapted for life in streams flowing over stony beds.

Bishop and Hart (1931) claimed that under both laboratory and field conditions the pulmonate *Limnaea palustris* Müller preys upon larval and pupal Culicidae, while Pruthi (1928) described how Indian snails of the genera *Acrostoma*, *Pila* and *Vivipara*—none of which occur in the Pacific—eliminate toxic substances which rapidly bring about the death of culicid larvae. It is not considered that any of the species which came under observation in these studies exercise any inhibitory effects on mosquito breeding, the absence of larvae from habitats containing snails always being explicable on other grounds.

**FISHES.** The fishes occurring in freshwater habitats in the tropical islands of the South Pacific are—with the exception of introduced cyprinodonts—of recent marine origin. Most of those collected (Table XVII) belong to the families Gobiidae and Eleotridae, which are represented throughout the high islands as far east as the Society Group (Seurat, 1931) and the Marquesas (Fowler, 1932). There are endemic genera and species in each of the major island groups. These frequently exhibit a preference for strictly freshwater habitats. Thus the Samoan *Vallima stevensoni* Jordan and Seale is found in mountain torrents above high waterfalls (Buxton and Hopkins, 1927), while a species of *Rhinogobius* taken from the upper reaches of the Tenaru River, Guadalcanal (coll. no. 32<sup>1</sup>) proved to be undescribed. The more widespread species of the area tend to be restricted to the coasts and may be found in freshwater- and brackish habitats alike. Thus *Eleotris fusca* ranges from Madagascar to the Marquesas, and was taken in fresh water near the mouths of streams in Viti Levu and Guadalcanal and at the edge of a brackish lake on Rennell. The widespread gobies *Ctenogobius nebulosus* and *Awaous ocellaris* were also found near stream mouths in Viti Levu and Guadalcanal, and on the latter island were associated with typically estuarine and marine fishes of the families Ambassidae and Mugilidae. *Mugil oligolepis* was recorded from a coastal freshwater marsh and from decidedly brackish water near the mouth of a tidal stream on Aneityum, while *Mugil* sp. was found in fresh water near the mouth of a ponded river and also in a brackish mangrove swamp on Guadalcanal.

The "millions fish" *Lebiasina reticulata*, which has been widely introduced about the Pacific as a mosquito enemy, featured in four of the New Caledonian collec-

TABLE XVII  
OCCURRENCE AND DISTRIBUTION OF PISCES

SYSTEMATIC POSITION AND COLLECTION NUMBER	NO. OF TIMES COL- LECTED	LOCALITY									
		Queensland	Solomon Is.	New Caledonia	New Hebrides	Fiji	Tonga	Samoa	Cook Is.	Gilbert Is.	Ellice Is.
<b>PISCES</b>											
<i>Lebiasina reticulatus</i> (Peters)	Poeciliidae 42, 59, 15 <sup>1</sup> , 57, 95, 122, 124	7	x	x			x				
Undetermined Gobiidae	60, 63, 95, 121, 21 <sup>1</sup> , 29 <sup>1</sup> , 27 <sup>1</sup> , 282, 283, 81 <sup>1</sup> , 82 <sup>1</sup> , 364	12	x	x	x	x	x	x			
<i>Ctenogobius</i> sp. Gobiidae 51 <sup>1</sup>		1		x							
<i>Hypseleotris cyprinoides</i> (Valenciennes)	Eleotridae 51 <sup>1</sup>	1					x				
<i>Lairdina hopletopus</i> Fowler	Eleotridae 38	1					x				
<i>Electris fusca</i> (Schneider)	Eleotridae 250, 13 <sup>1</sup> , 281, 51 <sup>1</sup>	4	x				x				
<i>Awaous ocellaris</i> (Broussonet)	Gobiidae 13 <sup>1</sup> , 281, 51 <sup>1</sup>	3	x				x				
<i>Ctenogobius nebulosus</i> (Forsskael)	Gobiidae 1 <sup>1</sup> , 43 <sup>1</sup> , 281	3	x				x				
<i>Mugil oligolepis</i> Bleeker	Mugilidae 73, 95	2			x						
<i>Dulus munda</i> (DeVis)	Dulidae 95	1			x						
<i>Acanthurus triostegus</i> (L.)	Acanthuridae 95	1		x							
<i>Pomadasys opercularis</i>	(Playfair; Pomadasytidae 95	1		x							
<i>Stigmatogobius duospilus</i> Fowler	Gobiidae 69	1		x							
<i>Ambassis miops</i> Günther	Ambassidae 43 <sup>1</sup> , 281	2	x								
<i>Belobranchus</i> sp.	Eleotridae 43 <sup>1</sup> , 281	2	x								
<i>Mugil</i> sp.	Mugilidae 43 <sup>1</sup> , 280, 281	3	x								
<i>Stenogobius genitissimus</i> (Valenciennes)	Gobiidae 43 <sup>1</sup> , 281	2	x								
<i>Ophiocara aporos</i> (Bleeker)	Eleotridae 280	1	x								
<i>Rhinogobius</i> sp.	Gobiidae 32 <sup>1</sup>	1	x								
<i>Mogurnda mogurnda</i> (Richardson)	Eleotridae 329, 356, 362, 367, 370	5	x								

tions and was also recorded from Aneityum and Aitutaki. This species was referred to as "Gambusia" at the time of its introduction into the Cook Islands (Anon., 1936; 1937) and in an earlier note on the mosquitoes of this group (Laird, 1954b). In the years immediately following this introduction a marked reduction in the numbers of *Culex annulirostris* became evident (Anon., 1936; 1937) and there is certainly a marked contrast between the rarity of larvae of this species in ponds where *L. reticulatus* is present and their abundance in habitats lacking the fish. The usefulness of this predator is curtailed by the occurrence of vegetation affording shelter to mosquitoes, and in fact larvae were present, although never abundantly, in six of the seven habitats in which *L. reticulatus* was noted (Table XVII). A further limiting factor is that the fish is restricted to breeding places of a permanent or semipermanent nature.

Some of the fishes indigenous to the region also prey upon mosquito larvae to some effect. *Ctenogobius nebulosus* and *Lairdina hopletopus* both thrived on an exclusive diet of mosquito larvae (*Culex annulirostris*) in the laboratory at Suva. These fish destroy pupae as well, but exhibit a preference for larvae when both developmental stages are available. When supplied with an excess of pupae alone a 32mm example of the former species captured and ate an average of 10 per day. *L. hopletopus* is of particular interest as a mosquito enemy in that it readily invades small transient pools near the edges of more extensive bodies of water.

This small eleotrid was abundant in a Fijian marsh (coll. no. 38) at one end of which was a complex of hoofprint pools. Almost every one of the pools examined proved to contain a fish of this species, and mosquito larvae were conspicuously absent from an otherwise favourable habitat. The cleorids were observed to fling themselves across the few inches of wet mud between the edge of the main water sheet and the nearest of the hoofprints, and to move between adjacent transient pools. In the laboratory they manifested a tendency to leap out of their containers once they had destroyed all the larvae in the water.

Two ponds from which mosquitoes were absent, one in Viti Levu (51<sup>1</sup>) and the other in Guadalcanal (43<sup>1</sup>), contained large numbers of small fish including gobies and eleotrids. There was a notable lack of shelter in both pools, and disregarding other factors contributing to the absence of larvae it is considered highly doubtful that mosquitoes could have become established in the face of such heavy predation.

Cooling (1923), Hamlyn-Harris (1929) and Shipway (1947) have discussed the efficiency of certain fish indigenous to Australia as mosquito predators. All of these authors singled out *Pseudomugil signifer* Kner for special mention. This is a fresh-and brackish water fish which, according to Hamlyn-Harris, "does wonderful work in controlling mosquitoes in all tidal waters." Shipway believed that *P. signifer* was at one time exported to the U.S.A. for use in a mosquito control campaign. None of the species discussed by these authors were collected in the course of the present studies, and the only fish recorded from Queensland pools, *Mogurnda mogurnda*, was not mentioned by any of them. Cooling (1927) referred to introductions of four species of fish from Australia into New Guinea and the Bismarck Archipelago, made by the German authorities before the First World War. It was claimed that after two initial failures these larvalid fish became established in 1914. It is considered that further investigations along these lines might have useful applications in the Pacific, and that the exploitation of local species—such as *Lairdina hoyleiatus*—closely adjusted to the more important larval habitats of the region might prove of more value than the introduction of exotic cyprinodonts the habitat preferences of which seldom bring them into contact with the most prolific sources of mosquito breeding.

**AMPHIBIA.** Darwin (1888) drew attention to Bory St. Vincent's assertion that frogs, toads and newts are absent from oceanic islands. Ascribing this to the impassability of marine barriers to amphibians he emphasised that the rule holds good only for the strictly oceanic islands, those which have originated independently of the continents, pointing out that islands such as New Zealand, New Caledonia and the Andamans, which formerly had continental connections, have indigenous frogs.

A few of the numerous amphibia native to Australia figured in the Queensland collections, while four species of frogs indigenous to the Solomons were taken from mosquito larval habitats in Guadalcanal (Table XVIII). Ranid tadpoles were found once each in New Caledonia and on Aore (New Hebrides) into which frogs of New Caledonian origin have been introduced by French settlers. Neither of the two rare species indigenous to Fiji were ever encountered. These, *Cornufer dorsalis* Duméril and *Platymantis vitiensis* (Duméril), "occupy the extreme outposts to which amphibian migration in the Pacific has reached" (Barbour, 1923).

As Darwin also mentioned, exotic frogs and toads deliberately introduced into oceanic islands may thrive to such an extent as to become a nuisance. The Surinam Toad, *Bufo marinus* L., which was originally brought to the Pacific from its West Indian home to help control insect pests in plantations, is no exception. It is extremely common today on numerous oceanic islands east of the limit of natural amphibian migration, including Hawaii and the Society Islands (Mumford, 1936), and is by far the most abundant representative of its class in Fiji, the Solomon Islands and coastal Queensland. Colonies from the flourishing populations in these

TABLE XVIII  
OCCURRENCE AND DISTRIBUTION OF AMPHIBIA  
LOCALITY

SYSTEMATIC POSITION AND COLLECTION NUMBER	No. OF TIMES COL- LECTED	LOCALITY									
		Queensland Is.	Solomon Is.	New Caledonia	New Hebrides	Fiji	Tonga	Samoa	Cook Is.	Gilbert Is.	Elice Is.
<b>AMPHIBIA</b>											
<i>Bufo marinus</i> (L.) Bufonidae 6 <sup>1</sup> , 38, 10 <sup>1</sup> , 198, 31 <sup>1</sup> , 32 <sup>1</sup> , 277, 282, 302, 60 <sup>1</sup> , 343, 345, 356,	16	x	x		x	x				x	
360, 364, 370											
<i>Rana</i> sp. Ranidae 9, 43	1	x		x	x						
<i>Ceratobatrachus guentheri</i> Boulenger Ranidae 224											
<i>Hyla thesaurensis</i> Peters Ilyidae 32 <sup>1</sup> , 213, 224	3	x									
<i>Platymantis papuanus weberi</i> (Schmidt) Ranidae 224	1	x									
<i>Rana gilli</i> Boulenger Ranidae 32 <sup>1</sup> , 209	2	x									
<i>Cyclorana</i> sp. Leptodactylidae 83 <sup>1</sup>	1	x									
<i>Iyla</i> sp. Hylidae 327				x							
<i>Sphenophryne</i> sp. Microhylidae 365				x							
Undetermined tadpoles 336, 347, 353	3	x									

places have been established in other islands on an unofficial and unrecorded basis, apparently by individuals acting on the assumption, widely held by Island settlers, that *B. marinus* is an active and formidable mosquito enemy. A case in point is the introduction of this toad into Funafuti, which does not appear to have been noted previously.

While there is no doubt that adult frogs and toads account for a certain number of adult mosquitoes, most tadpoles are herbivorous and of little significance as predators. Through their surface-browsing habits they occasionally (probably quite adventitiously) destroy mosquito eggs and newly hatched larvae. Mosquitoes were present in 20 (77 per cent.) of the pools containing tadpoles, and were abundant or common in ten of these. Probably the only effective contribution to mosquito control made by tadpoles is that when pools are literally swarming with them the constant agitation of the water surface endangers both ovipositing females and emerging adults (Laird, 1947). The marsh 6<sup>1</sup>, one of the six amphibian habitats from which no mosquitoes were recorded, is a case in point.

#### PARASITOLOGY

The term "parasitology" is used herein in its broadest sense so as to include with those organisms which are pathogenic in varying degree, those which have a primarily commensal relationship with the host.

While true parasites of mosquitoes were but seldom encountered, larvae and pupae—but more particularly the former—were quite commonly found to support various ectocommensal organisms.

#### ECTOPHYTA

**BACTERIA.** *Sphaerotilus* aff. *dichotomus* (Cohn) (Pl. 1, Figs. 6 and 7). Ectophytic bacteria exhibiting false branching were noticed on three occasions. They were attached to the hairs (particularly those of the ventral brush) of second, third and fourth instar larvae of *Anopheles farauti* at Luganville, Espiritu Santo (coll. no. 30); and at Henderson Field, Guadalcanal (coll. no. 267) (Fig. 7); and an identical species was present on the hairs and cuticle of the posterior segments of larvae (all instars) of *Bironella hollandi*, *Uranotaenia civinskii* and *Culex pullus* at Ilu Farm, Guadalcanal, (coll. no. 263) (Fig. 6).

The few observations made on these bacteria were undertaken in the field on living material, by means of phase-contrast microscopy. As the bacterial filaments underwent disintegration during storage in the 70 per cent. alcohol used for the preservation of larvae, it is very possible that the organism has a wider distribution than my notes indicate; for time or other cause precluded the field study of living material on trips other than those in Fiji or to Ancityum, Espiritu Santo, New Caledonia and Guadalcanal.

Individual cells of the filaments are rod-shaped, and appear black by phase contrast microscopy. They can scarcely be made out at all by bright field illumination. The enclosing sheath is hyaline. In most cases it was distinguished with difficulty, and it is not indicated in the accompanying illustrations. The cells range from  $1\cdot5\mu$  to  $7\cdot7\mu$  in length and from  $0\cdot8\mu$  to  $1\cdot1\mu$  in breadth, average examples being of the order of  $2\cdot3\mu$  by  $1\cdot0\mu$ . None of the cells themselves exhibit branching, this apparently being a property of the sheath alone. Branching is dichotomous (Fig. 6). The longest thread seen measured  $130\cdot7\mu$  from the point of attachment to the ultimate cell of the final dichotomy.

Generally speaking the filaments were immobile while no movements of either the host or the watery medium were taking place. Sometimes, though, a single cell was seen to undergo slow but definite rocking or rotatory movement. This was most evident among two- or three-cell filaments such as those illustrated in Fig. 7.

All the larvae concerned were also infested with peritrichous ciliates. None of them appeared incommoded by the presence of either the bacteria or the protozoans. Pupation took place normally (no bacteria being attached to the pupae) and healthy imagines emerged in due course. Collections nos. 30 and 263 were both made from transient pools in areas subject to intermittent inundation (pH 7·4 @  $25^\circ\text{C}$  and pH 7·2 @  $24^\circ\text{C}$  respectively), while no. 267 was made from a tidal inlet (pH 8·2 @  $31^\circ\text{C}$ ).

The morphology of the organism places it in the order Chlamylobacteriales. Frobisher (1949) stated that the members of this order are characteristically "filamentous with cylindrical sheaths, the sheaths filled with rod-shaped bacteria end to end. . . . Their habit is aquatic. They may grow in the sea, rivers, lakes, stagnant ponds and marshes, or in good, sparkling well water, springs, or even filtered water supplies. . . . The sheath is branched but the individual bacillus-like cells are not."

Two of the families of the Chlamylobacteriales form sheathed filaments, but all but one of the genera within these deposit iron in the sheath as Fe(OII)<sub>3</sub>. The organism under consideration proved referable to the remaining genus, *Sphaerotilus* Kützing, 1833. This genus is defined by Bergey (1934) as "Attached colorless threads, showing false branching, making pseudo-dichotomy. Filaments consist of rod-shaped or oval cells, surrounded by a thin, firm sheath." According to Frobisher, the individual cells of *Sphaerotilus* range up to  $10\mu$  in length and measure about  $2\mu$  in breadth. While these measurements exceed those of the present bacteria, the latter correspond with *Sphaerotilus* in other respects. In the regularity of their dichotomous pseudo-branching they agree most closely with *S. dichotomus* (Cohn). The optimum temperature for this species is given by Bergey as  $25^\circ\text{C}$  to  $30^\circ\text{C}$ , the habitat being swamp water.

Frobisher (1949) mentioned that members of the Chlamylobacteriales "often grow near aquatic green plants since these liberate oxygen into the water." The *Sphaerotilus* under discussion was observed to exhibit a marked preference for the posterior portions of the larval body. It was always much commoner on the hairs of the ventral brush (making these appear densely and raggedly plumose) and on and about the anal papillæ than elsewhere. This point will be referred to again in the discussion concerning ectocommensal peritrichous ciliates.

There is little information in the literature about ectophytic bacteria from insects. Steinhaus (1947) referred briefly to this flora, regarding the bacteria

concerned as mostly adventitious and discussing only aerial and terrestrial insects (cockroaches, houseflies, bees). Perroncito (1899) and some other authors have recorded pathogenic bacterial endoparasites from larval mosquitoes, and more recently von Jettnar (1947) reviewed the relevant literature and dealt at some length with "streptobacilli" from *Culex p. fatigans* from a pool in Shanghai. These bacteria were particularly prevalent on third and fourth instar larvae, great numbers of vorticellid ciliates being associated with them as secondary invaders. Jenkins and Knight (1950) observed iron or sulphur bacteria on some larvae of *Aedes punctor* (Kirby) in Quebec.

Morphologically, von Jettnar's bacteria compare closely with those described herein. They were described as forming chains of individuals usually having sharp corners (although some were so rounded as to appear like streptococci). Separate cells were usually longer than broad, averaging  $1.6\mu$  in length (some exceeding  $2\mu$ ) by  $1.2\mu$  in breadth. The chains were of rather constant width, a distinct capsule (seen clearly in Carnoy/Giemsa preparations) increasing their overall thickness to about  $1.6\mu$ . Von Jettnar observed that his bacteria exhibited true ramification only very rarely. He thus considered them to belong not to the Actinomycetes but to the Schizomycetes, and pointed out that they resembled the sulphur and iron bacteria (Cithaeroidobacterales) in forming tufts of long filaments vertical to the substrate. Aside from the fact that the Shanghai organism was not characterized by false branching, the two species obviously have much in common from a morphological standpoint. They differ radically as regards pathogenicity, though, for while the South Pacific species is a harmless ectocommensal that described by von Jettnar was stated by him to penetrate the cuticle of the host, to infect the epithelial cells concerned with the production of chitin and to invariably bring about the death of the larva before pupation could take place.

The only previous record of allied ectophytic bacteria from aquatic insects in the Pacific is that of Williams (1936). This author found clusters of sewage-like bacteria associated with *Vorticella* and diatoms among the hairs of old nymphs of the Hawaiian dragonfly *Nesogonia blackburni* (McLachlan).

ALGAE. *Characium* aff. *saccatum* Filarszky (Pl. 1, Figs. 1-5).

Filamentous green algae were never recorded from mosquito larvae, but on two occasions the solitary cells of a sessile species were noted. Heavy infestations were found on third and fourth instar larvae of *Anopheles farauti* and *Culex annulirostris* at Luganville, Espiritu Santo (Coll. no. 30). The culicines also harboured numerous peritrichous ciliates of the genera *Vorticella* and *Epistylis*, while the anophelines supported a growth of *Vorticella* and *Sphaerotilus* bacteria. A few scattered examples of the same alga were recorded from second and third instar larvae of *C. annulirostris* near the mouth of the Lunga River, Guadalcanal (Coll. no. 277). The first of these collecting stations was a transient pool (pH 7.4 @ 25°C) while the second was a ponded stream (pH 9.2 @ 29°C).

Nearly all the individuals seen were in various stages of zoospore formation (Figs. 1 and 2). Living cells measuring up to  $60\mu$  by  $20\mu$  were noticed, the organism generally being about three times as long as broad. Zoospore formation took place in spiral fashion (Figs. 1 and 2). The cells were particularly abundant on the dorsal surface of the thorax and abdomen and on the ventral surface of the head, in *An. farauti* larvae; although plentiful on the antennae, the ventral head hairs and the anterior and lateral margins of the head (Fig. 5); they were only rarely attached to the dorsal surface. *C. annulirostris* larvae were most heavily infested posteriorly, the anal papillae bearing very large numbers of algal cells and sometimes epistylids as well (Fig. 4).

Material was sent to Professor G. W. Prescott, who identified the genus as *Characium* (Chlorophyta: Characiaceae). In the absence of living specimens he was unable to make a definite specific determination, but felt that in all probability the species concerned was *C. saccatum* Filarszky. The type host for this ectophytic

is the phyllopod crustacean *Branchipus stagnalis* L. The Phyllopoda were not represented in either collection, but a cladoceran (*Moina* sp.) was plentiful in the New Hebridean pool (coll. no. 30). These crustaceans were infested with a *Characium* indistinguishable from that which was so common on the larval mosquitoes in the same pool.

Iyengar and Iyengar (1932) described *Characium anophelesi* from the larvae of six species of *Anopheles* in Lower Bengal. They considered this alga to be specific for anophelines, since aquatic plants and larval *Culex* and *Plecoptera* from the same pools were never infested. *C. anophelesi* differs from *C. saccatum* in having a less conspicuous basal attachment disc and in being of much squatter form (length: breadth ratio, 9:4 to 1:3). The basal disc of the former species is a very minute mucilaginous disc, while that of the latter may be large and pocket-shaped, the lower end of the cell being embedded in it. It should be noted that the basal disc of *C. saccatum* seldom shows up well in material preserved in bulk in alcohol (cf., Fig. 5), and that Fig. 3 was sketched from a living example under phase-contrast illumination.

*Vorticellids* are frequently associated with *C. anophelesi* (Iyengar and Iyengar, 1932) which, like *C. saccatum* in the Pacific, is especially abundant on the back, flanks and anal region of anopheline larvae while it is scanty or absent on the ventral region. The Indian investigators suggested that the reason for this is the greater amount of illumination received by the dorsal surface of *Anopheles* larvae while feeding at the surface. Their explanation is supported by the fact that the Pacific *An. farauti* larvae had the ventral surface of the head—which is of course presented to the surface film in the normal feeding position—heavily infested, while the dorsal surface seldom bore algal cells. These authors also suggested that the absence of *C. anophelesi* from *Culex* larvae is perhaps due to the lesser amount of sunlight available at the surface of the body because of the head-downwards position adopted during feeding. Although *C. saccatum* is less host-specific than *C. anophelesi*, it certainly shows a preference for the posterior abdominal segments—which are closer to the surface in the feeding position—of culicine larvae.

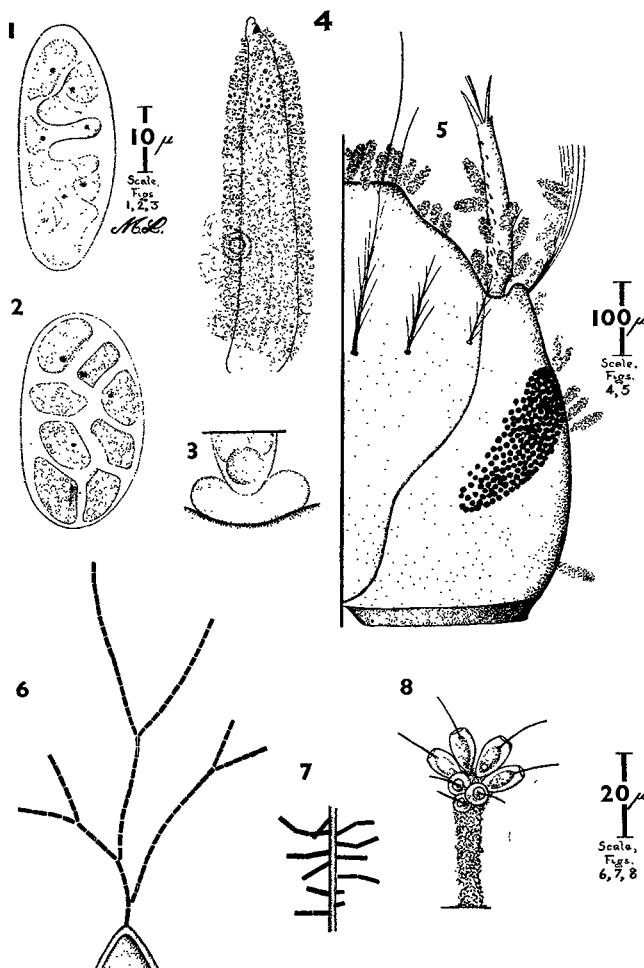
*C. anophelesi* was not regarded as pathogenic by Iyengar and Iyengar, the only effect of the presence of a growth of this alga being a slight hampering of the movements of the host. The movements of *An. farauti* and *C. annulirostris* were similarly hampered by the *Characium* under discussion, the latter mosquito sometimes indulging in twisting movements to bite at the siphon, anal segment and anal papillae as in the case of heavy ciliate infestations (p. 110). In several instances the anal papillae of *C. annulirostris* larvae of the fourth instar were somewhat shrivelled in appearance and distorted at the tip (Fig. 4) when heavily covered with algal cells. Pupation was never impeded, though, and normal imagines always emerged in due course. *Characium* cells were only rarely seen on pupae.

#### ECTOZOA

PROTOZOA. Mastigophora. *Cadonoeca* aff. *asocians* (Pl. 1, Fig. 8).

Several second and third instar larvae of *Culex pullus* from a transient pool at Ilu Farm, Guadalcanal (coll. no. 272; pH 7.2 @ 25°C) bore small colonies of

Figs. 1-5.—*Characium* aff. *saccatum* Filarszky, from *Anopheles farauti* (1, 2, 3, 5) and *Culex annulirostris* (4) (coll. no. 30). FIGS. 1 and 2.—Zoospore formation. Iron haematoxylin, 1,300 X. FIG. 3.—Basal attachment disc. Iron haematoxylin, 1,380 X. FIG. 4.—Heavily infested anal papilla, *C. annulirostris*. Unstained "Sira" mount, 152 X. FIG. 5.—Habit. Head of *An. farauti*. Unstained "Sira" mount, 152 X. FIGS. 6 and 7. *Sphaerotilus* aff. *dichotomus* (Cohn) on fibres of "Sira" of *C. annulirostris* (Fig. 6). "Sira" of *C. annulirostris* (Fig. 7).



See next page for caption (p. 103).

a flagellate at the lateral margins of the thorax. No other ectocommensals were present.

A gelatinous, granule-encrusted stalk averaging about  $6\mu$  in width and ranging up to  $35\mu$  in length stood out at right angles to the cuticle of the host (Fig. 8). No details regarding the nature of the attachment could be made out with living material, and attempts to preserve and stain the organism were unsuccessful. At the distal end of the stalk were from five to nine closely approximated monomastigote flagellates, each within an ovoidal lorica measuring a little over  $10\mu$  in length by up to  $6\mu$  in width. The body of each flagellate was broadly fusiform, and there was a posteriorly positioned contractile vacuole of about  $1.4\mu$  diameter. A rather thick flagellum about  $13\mu$  long protruded from the opening of the lorica for a distance equivalent to the length of the lorica itself.

The morphology of this organism refers it to the family Bicosoecidae of the order Protomonadina as defined by Kudo (1916). It is not possible to be certain of its systematic position in the absence of stained material, but it comes close to *Codonoea* aff. *associans*.

I have been unable to locate any previous record of ectocommensal flagellates from mosquito larvae.

**PROTOZOA.** Ciliata. Representatives of the order Peritrichia were commonly attached to the developmental stages of numerous species of mosquitoes. They belonged to the genera *Zoothamnium*, *Vorticella* (fam. Vorticillidae Flomental) and *Epistyliis* (fam. Epistyliidae Kent). All the records are noted in Table I.

Of the 372 collections which included larval mosquitoes, 213 were made from surface water (habitat categories 1-5, 9-10) while 159 were made from containers (habitat categories 6-8, 11 and 12). Larvae from 61 (17 per cent.) of the collections were infested with *Vorticella*, 58 of the collections concerned being from surface water and only six from containers. Only natural (rock holes) and artificial (drums, etc.) large simple containers were involved. Larvae from 35 habitats (15 of these negative for *Vorticella*) bore growths of *Epistyliis*. This genus was only recorded once from a container (coll. no. 120, a large metal tank sunk into the ground). *Zoothamnium* was found on but a single occasion, a single dichotomous stalk bearing two individuals being attached to the abdomen of a fourth instar larva of *Culex annulirostris* from Lake Teungano, Rennell (coll. no. 250). Eighty (22 per cent.) of the larval habitats studied thus included larvae infested with peritrichous ciliates.

*Zoothamnium* sp. This genus is recorded from a "Sira" mount of the *C. annulirostris* larva referred to above. The two zooids are contracted and distorted as is unavoidable in such mounts, and their nuclei cannot be made out by phase contrast. They were at first taken for epistyliids, but a closer examination disclosed a bifurcated spasmoneme exhibiting spiral contraction within the short, thick stalk. Crustaceans are the usual hosts for *Zoothamnium*, which is comparatively rare on insects. Nenninger (1918), following the examination of 21 species of crustaceans and 58 of insects, reported that five species of the former group harboured a total of nine species and varieties of these ciliates, while only one representative of the genus was present on a single insect host, a mayfly nymph. There does not appear to be any previous record of *Zoothamnium* from the Culicidae.

*Vorticella microsoma* Ehrenberg, 1830 (Pl. 2, Figs. 11 and 13; Pl. 7, Fig. 42).

Normal trophozoites of Pacific material of this vorticillid are pyriform, the body being inflated medially (Figs. 13 and 42). The fully expanded peristome is appreciably narrower than the broadest part of the body. Large examples frequently exhibit a posterior constriction at the zone of development of the posterior ciliary

( $49.2\mu$ ); greatest breadth,  $23.0\mu$  to  $45.3\mu$  (av.,  $32.8\mu$ ); breadth of peristome  $14.1\mu$  to  $27.8\mu$  (av.,  $22.2\mu$ ); diameter of contractile vacuole,  $8.0\mu$  to  $12.3\mu$  (av.,  $10.2\mu$ ); length of stalk, up to  $175\mu$  (av., c. $80\mu$ ); diameter of stalk,  $2.7\mu$  to  $4.5\mu$  (av.,  $3.3\mu$ ); diameter of spasmoneme,  $1.6\mu$  to  $1.8\mu$  (av.,  $1.7\mu$ ).

Individuals having from 23 to 55 pellucidal striae were noticed, the distance between striae varying from  $1.1\mu$  to  $1.5\mu$  and the actual number present increasing with the size of the animal. The macronucleus is elongate and longitudinally positioned in the larger examples (Fig. 13), but it is frequently thick and U-shaped and transversely placed towards the anterior extremity in smaller ones (Fig. 11).

The contractile vacuole interval is somewhat variable, but is usually within the limits of 9 to 16 seconds in vorticellids freshly placed on the microscope stage using as little light as possible in order to reduce the adverse effects of light and heat. Successive intervals (in seconds) for three such individuals were, 10, 10, 10, 11, 10; 14, 14, 16, 14, 15; 12, 10, 11, 9, 12. Another example which was subjected to the maximum light and heat of the microscope's integral illuminator exhibited successive intervals of 10, 10, 14, 16, 20, 21 and 31 seconds. Intervals were also noted for two recent products of ordinary vegetative division. The daughter individual had a completely formed posterior ciliary wreath and had commenced to feed, but cleavage had not yet taken place; successive contractile vacuole intervals for the parent were 16, 14, 15, 15 and 13 seconds and for the daughter 16, 15, 16, 14 and 16 seconds.

Many of the examples studied, notably those on very young larvae, had short stalks, often shorter than the body itself. These were otherwise morphologically similar to long-stalked individuals, and had obviously only recently attached themselves to the host. The length of the spasmoneme spiral is in the vicinity of  $30\mu$  in those vorticellids having a stalk of average length, three spirals characteristically being present. The stalk itself exhibits a slight but appreciable sinuosity. Although phase contrast microscopy affords an ideal means of the demonstration of the plastid granules in the stalk of living vorticellids, such granules were never observed although they were carefully searched for. They are thus considered to be lacking.

Finally, the ratio of length to breadth is usually in the vicinity of 1.5 to 1, but in actively feeding individuals, which may appear almost globular, it may fall to 1.1 to 1 (Fig. 42). Certain of the smaller specimens seen exhibited practically no inflation of the median zone of the body, the breadth of the peristome being about the same as, or even exceeding (Fig. 11), that of the body proper at its greatest diameter. The macronucleus of such vorticellids was practically always anterior in position and transversely placed. The animals in question were always associated with others exhibiting the characters of the species under discussion.

With the exception of the small forms having a relatively broad peristome just referred to, the species described herein answers closely to *V. microstoma* Ehrenberg as redescribed by Noland and Finley (1931). Its average size and maximum dimensions are somewhat less than in the material before these authors, who recorded the length as  $35\mu$  to  $83\mu$  (mode,  $55\mu$ ), and the breadth as  $22\mu$  to  $50\mu$  (mode,  $35\mu$ ), and the stalk never reaches the length of  $305\mu$  sometimes attained by their American strain. A probable reason for this is the nature of the substratum. Noland and Finley were dealing with specimens growing in laboratory infusions which would not have to face the mechanical problems associated with uncoiling and retraction from a constantly and erratically moving aquatic insect. Too great a stalk length would surely be of material disadvantage to vorticellids utilizing such a habitat. Bary (1950) based his identification of *V. microstoma* from New Zealand on comparisons with the data presented by Noland and Finley, but gave no measurements from his own specimens. His Pl. 39, Fig. 16 shows an example of similar morphology to that illustrated in Fig. 13 herein, but of considerably larger size  $93\mu$  by  $63\mu$ , according to his scale line. Bhatia (1936) gave  $100\mu$  as the maximum length attained by the species in India. Stout (1951) also discussed a New Zealand strain of *V.*

<i>Aedes vexans</i>	...	...	...	...	2	(22	"	)
<i>Aedes vexans nocturnus</i>	...	...	...	2	(13	"	)	
<i>Aedes vigilax</i>	...	...	...	2	(25	"	)	
<i>Culex minutus</i>	...	...	...	2	(67	"	)	
<i>Bironella hollandi</i>	...	...	...	1	(25	"	)	
<i>Culex basicinctus</i>	...	...	...	1	(11	"	)	

Collections positive for *V. microstoma* were made from habitats the hydrogen ion content of which ranged from pH 6.0 to pH 9.5, almost half of these falling within the range pH 7.2-7.4. The outstandingly significant correlation between the occurrence of infestations and a habitat factor was, however, that with pollution by animals. Of the 61 collections in which the ciliate figured, 57 (93 per cent.) were from habitats in which such pollution (usually by the dejecta of domestic animals, notably pigs, cattle and horses) was patent. The water in three of the other habitats (coll. nos. 6, 17, 18) was clean and odourless, while that in the remaining one (coll. no. 36) contained decomposing leaves but was out of the reach of any of the vertebrates which occurred locally. Larvae from the 106 other stations listed as polluted in Table I were negative for *Vorticella*. Thirty-six of these (from 14 of which larvae bearing other peritrichous ciliates were collected) showed signs of pollution by animals, while in 70 of them (59 in this group being either simple or specialized containers) the only source of pollution was vegetable decomposition. Thus 57 (61 per cent.) of the 93 mosquito larval collections from habitats polluted by animals included larvae infested with *V. microstoma*, while only one (1.1 per cent.) of the 70 such collections from habitats polluted only by decomposing vegetation was positive for this ciliate.

These facts are in accord with the known habits of *V. microstoma*, which according to authorities quoted by Stout (1934) is one of the most common sewage Protozoa. They have a direct bearing on the host occurrence of the ciliate, all but one of the mosquitoes from which it was recorded characteristically utilizing standing surface water subject to animal pollution as larval habitats. The only occasion upon which *V. microstoma* was noted on a larva typically occurring amongst green algae in clean, flowing water was when a few trophozoites were observed on two of 28 *C. basicinctus* larvae closely associated with heavily infested *C. annulirostris* in a ponded ditch bordering a cattle paddock near Luganville, Espiritu Santo (coll. no. 31).

The degree of infestation was observed to vary with the age of the larva, third and fourth instars generally speaking being more thickly covered with vorticellids than first and second instars. This does not reflect steadily increasing ciliate populations, for the vorticellids are thrown off with each moulted skin. It is a factor of the greater surface area open to ectozoan invasion in the case of older larvae, combined with the fact that at each moult some at least of the protozoans from the old skin leave their stalks and at once re-attach themselves to the host. Although pupae were often infested, these seldom bore more than a few scattered ciliates. In 11 collecting stations supporting more than one species of mosquito, each species present was positive for *V. microstoma*, while in 16 other such stations one or more of the species present was negative for this ciliate. Sometimes there was no obvious explanation for this—thus two closely adjacent transient pools at Aore, New Hebrides, held larvae of both *An. jarauti* and *C. annulirostris*; in one of them (coll. no. 10) only the latter species bore vorticellids, in the other (coll. no. 11) only *An. jarauti* was infested. In other cases the explanation probably lies in differing larval habits. Thus the infested *C. annulirostris* larvae from coll. no. 46 kept together near the cattle-trampled margin of a ponded ditch, while the non-infested *C. bitaeniorhynchus* larvae were only to be found in masses of *Spirogyra* where the localized high oxygen level resulting from photosynthesis might have exercised a repellent effect upon the bacteria-feeding *V. microstoma*.

*microstoma*, his trophozoites being of the order of size of those of Noland and Finley. The macronucleus of the normal form is illustrated as sausage-shaped and transversely positioned in Stout's Text-fig. 2, 1.

Noland and Finley (1931) also dealt with a smaller vorticellid measuring from  $23\mu$  to  $33\mu$  (mode,  $35\mu$ ) by from  $13\mu$  to  $32\mu$  (mode,  $19\mu$ ) and having a relatively broader peristome ranging from  $13\mu$  to  $26\mu$  in breadth (mode,  $18\mu$ ). They pointed out that this animal has a short thick macronucleus transversely placed in the upper part of the body, and has more clearly marked pellicular striae and less toleration to laboratory infusions than has *V. microstoma*. In other respects it resembles "a small edition of the latter." These authors designated the smaller organism *Vorticella striata* var. *octava* (Stokes), despite the fact that Dujardin had originally described *V. striata* from sea water.

Most of the present material is recorded from mosquito larvae from obviously polluted water (p. 107), which is in accord with observations from Malaya to the effect that anopheline larvae are rarely if ever heavily infested with vorticellids except in relatively impure water (Williamson, 1935). Both the individuals having a longitudinally positioned macronucleus and those with a transverse one occur without reference to the degree of pollution. Stout's (1954) specimens exhibiting a transversely placed macronucleus were from the highly organic fluid of a meat digestion plant. The pellicular striae were usually well marked in the Pacific material, as they also were in the examples figured by Bary (1950) and Stout. The latter author made the interesting observation that starved and recently excysted specimens of *V. microstoma* are small and relatively thin ( $40\mu$  by  $20\mu$ ), the peristome in such cases being much broader than usual in relation to the breadth of the body proper. His Text-fig. 2, 3 illustrates a recently excysted form of very similar proportions to that seen in Fig. 11 of this paper.

In view of these facts, and the admission of Noland and Finley themselves that specimens occur which are almost intergrades between *V. microstoma* and the smaller form to which they gave the name of *V. striata* var. *octava*, and, as the size ranges of the two forms as understood by these authors overlap appreciably, there is hardly justification for the designation of two species on morphological grounds. As to the matter of physiological differentiation, it is surely more reasonable to recognize the occurrence of biological strains within the one freshwater species *V. microstoma* than to assign the atypical small forms under consideration to a marine species, *V. striata*. If a varietal name must be applied to the smaller form—and such a procedure could lead to endless "splitting" within such patently polymorphic species as *V. microstoma*—*V. microstoma* var. *abbreviata* Kaisen (1921) antecedes the paper of Noland and Finley.

*V. microstoma* was recorded from all but three of the collecting stations (coll. nos. 255, 267 and 276)—indicated as positive for *Vorticella* in Table I, and in all cases was the only vorticellid present on the infested larvae. The mosquito species from which this ciliate was recorded are listed below in order of the frequency with which infestations were noted. The number following each specific name is the number of infested collections, while the bracketed percentages indicate the percentage of the total number of collections of each of the mosquitoes so infested.

<i>Culex annulirostris</i>	—	—	—	35	(29 per cent.)
<i>Anopheles farauti</i>	—	—	—	14	(24 " "
<i>Culex fraudatrix</i>	—	—	—	6	(29 " "
<i>Anopheles annulipes</i>	—	—	—	4	(17 " "
<i>Culex pipiens fatigans</i>	—	—	—	4	(15 " "
<i>Culex pullus</i>	—	—	—	4	(33 " "

Only eight (14 per cent.) of the 57 infested collections from animal-polluted habitats were from brackish water, the number of ciliates present being few in all cases, and eight (21 per cent.) of the 36 animal-polluted but *Vorticella*-free habitats were brackish. Although *V. microstoma* was thus present in half of the brackish and animal-polluted habitats, the lightness of the infections suggests that a degree of salinity is unfavourable to this protozoan.

Infested larvae generally bear the heaviest concentrations of ciliates on and about the anal papillae and at the intersegmental grooves of the abdomen. The thorax is sometimes involved also, but the head rarely bears any vorticellids. Infestations were classed as heavy when larvae bore masses of *V. microstoma* as in Fig. 42 (as many as 1,500 individuals have been counted on a single larva); as medium when numerous ciliates were present although not packed together in dense concentrations, and as light when only a few scattered examples were evident. While animal pollution is the significant factor as regards the occurrence and non-occurrence of *V. microstoma* on its mosquito hosts in the South Pacific, the hydrogen ion content of the water has bearing on the degree of infestation. Twenty of the freshwater habitats concerned were classed as exhibiting heavy infestation, seven as exhibiting medium infestation and 26 as exhibiting light infestation. Within each of these groups the numbers of occurrences of *V. microstoma* for each pH value were as follows:—

TABLE XIX Correlation of <i>Vorticella microstoma</i> infestation with pH.														
pH value	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6
Heavy infestation	—	—	—	—	1	—	1	5	11	1	—	1	—	—
Medium infestation	—	—	—	—	1	2	1	2	—	—	1	—	—	—
Light infestation	—	3	3	—	2	3	2	3	3	—	1	1	2	2
Totals	—	3	3	—	3	4	5	9	16	1	1	3	2	2

Thus, while infested collections were made from waters of pH 6.0–8.6+ (9.5), 16 (80 per cent.) of the heavy infestations and 25 (47 per cent.) of all the relevant collections were from habitats of pH 7.2 or pH 7.4. It is therefore apparent that although *V. microstoma* occurs through quite a wide range of acid and alkaline waters, it flourishes best under conditions of slight alkalinity.

It is concluded that non-saline waters of high nitrogenous content and exhibiting slight alkalinity afford the optimum conditions for the development of *V. microstoma* on mosquito larvae. Larval habitats answering to this description were not encountered on Bellona, Sikiana, Savai'i, Nukunono, Tarawa or Funafuti, and only one such habitat (coll. no. 85) was seen on Futuna. These are the only islands from which reasonable numbers of larval collections were made where vorticellids were not recorded.

As to the preference exhibited by the ciliate for the anal papillae and their vicinity, it is suggested that as vorticellids are typically bacterial feeders (Sandon, 1932) this may well be due to a greater availability of bacteria about the posterior extremity of the body in consequence of larval defaecation. The influence of the constant uptake of water and chloride ions by the papillae themselves (Wigglesworth, 1938) may also have bearing on the problem, and although the weight of evidence is not in favour of the thesis that these papillae have any respiratory function even a small amount of oxygen diffusion taking place across their membranes could in itself account for the local concentration of both bacteria and such a facultative anaerobe as *V. microstoma* (Engelmann, 1895). It is of significance in this connection that mosquito pupae, which neither feed nor have anal papillae, never bear more than a few scattered vorticellids.

Mosquito larvae heavily infested with *V. microstoma* were often observed to be suffering considerable inconvenience thereby. They frequently arched themselves

concerned as mostly adventitious and discussing only aerial and terrestrial insects (cockroaches, houseflies, bees). Perroncito (1899) and some other authors have recorded pathogenic bacterial endoparasites from larval mosquitoes, and more recently von Jetmar (1947) reviewed the relevant literature and dealt at some length with "streptobacilli" from *Culex p. fatigans* from a pool in Shanghai. These bacteria were particularly prevalent on third and fourth instar larvae, great numbers of vorticellid ciliates being associated with them as secondary invaders. Jenkins and Knight (1950) observed iron or sulphur bacteria on some larvae of *Aedes punctor* (Kirby) in Quebec.

Morphologically, von Jetmar's bacteria compare closely with those described herein. They were described as forming chains of individuals usually having sharp corners (although some were so rounded as to appear like streptococci). Separate cells were usually longer than broad, averaging 1.6 $\mu$  in length (some exceeding 2 $\mu$ ) by 1.2 $\mu$  in breadth. The chains were of rather constant width, a distinct capsule (seen clearly in Carnoy/Giemsa preparations) increasing their overall thickness to about 1.6 $\mu$ . Von Jetmar observed that his bacteria exhibited true ramification only very rarely. He thus considered them to belong not to the Actinomycetes but to the Schizomycetes, and pointed out that they resembled the sulphur and iron bacteria (Chlamydothiobacteriales) in forming tufts of long filaments vertical to the substrate. Aside from the fact that the Shanghai organism was not characterized by false branching, the two species obviously have much in common from a morphological standpoint. They differ radically as regards pathogenicity, though, for while the South Pacific species is a harmless ectocommensal that described by von Jetmar was stated by him to penetrate the cuticle of the host, to infest the epithelial cells concerned with the production of chitin and to invariably bring about the death of the larva before pupation could take place.

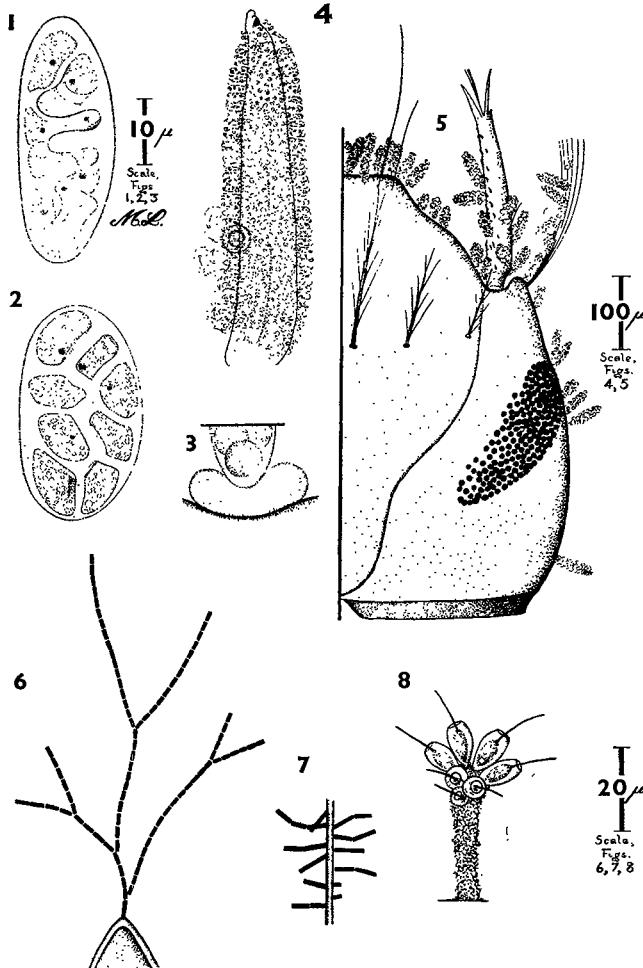
The only previous record of allied ectophytic bacteria from aquatic insects in the Pacific is that of Williams (1936). This author found clusters of sewage-like bacteria associated with *Vorticella* and diatoms among the hairs of old nymphs of the Hawaiian dragonfly *Nesogonia blackburni* (McLachlan).

ALGAE. *Characium* aff. *saccatum* Filarszky : Pl. 1, Figs. 1-5.

Filamentous green algae were never recorded from mosquito larvae, but on two occasions the solitary cells of a soscille species were noted. Heavy infestations were found on third and fourth instar larvae of *Anopheles farauti* and *Culex annulirostris* at Luganville, Espiritu Santo (Coll. no. 30). The culicines also harboured numerous peritrichous ciliates of the genera *Vorticella* and *Epistylis*, while the anophelines supported a growth of *Vorticella* and *Sphaerotilus* bacteria. A few scattered examples of the same alga were recorded from second and third instar larvae of *C. annulirostris* near the mouth of the Lunga River, Guadalcanal (Coll. no. 277). The first of these collecting stations was a transient pool (pH 7.4 @ 25°C); while the second was a ponded stream (pH 9.2 @ 29°C).

Nearly all the individuals seen were in various stages of zoospore formation (Figs. 1 and 2). Living cells measuring up to 60 $\mu$  by 20 $\mu$  were noticed, the organism generally being about three times as long as broad. Zoospore formation took place in spiral fashion (Figs. 1 and 2). The cells were particularly abundant on the dorsal surface of the thorax and abdomen and on the ventral surface of the head, in *An. farauti* larvae; although plentiful on the antennae, the ventral head hairs and the anterior and lateral margins of the head (Fig. 5) they were only rarely attached to the dorsal surface. *C. annulirostris* larvae were most heavily infested posteriorly, the anal papillae bearing very large numbers of algal cells and sometimes epistylids as well (Fig. 4).

Material was sent to Professor G. W. Prescott, who identified the genus as *Characium* (Chlorophyta: Characiaceae). In the absence of living specimens he was unable to make a definite specific determination, but felt that in all probability the species concerned was *C. saccatum* Filarszky. The type host for this ectophyte



See next page for caption (p. 103).

is the phyllopod crustacean *Branchipus stagnalis* L. The Phyllopoda were not represented in either collection, but a cladoceran (*Moina* sp.) was plentiful in the New Hebridean pool (coll. no. 30). These crustaceans were infested with a *Characium* indistinguishable from that which was so common on the larval mosquitoes in the same pool.

Iyengar and Iyengar (1932) described *Characium anophelesi* from the larvae of six species of *Anopheles* in Lower Bengal. They considered this alga to be specific for anophelines, since aquatic plants and larval *Culex* and *Plectoptera* from the same pools were never infested. *C. anophelesi* differs from *C. saccatum* in having a less conspicuous basal attachment disc and in being of much squatter form (length: breadth ratio, 9:4 to 4:3). The basal disc of the former species is a very minute mucilaginous disc, while that of the latter may be large and pocket-shaped, the lower end of the cell being embedded in it. It should be noted that the basal disc of *C. saccatum* seldom shows up well in material preserved in bulk in alcohol (cf., Fig. 5), and that Fig. 3 was sketched from a living example under phase-contrast illumination.

Vorticellids are frequently associated with *C. anophelesi* (Iyengar and Iyengar, 1932) which, like *C. saccatum* in the Pacific, is especially abundant on the back, flanks and anal region of anopheline larvae while it is scanty or absent on the ventral region. The Indian investigators suggested that the reason for this is the greater amount of illumination received by the dorsal surface of *Anopheles* larvae while feeding at the surface. Their explanation is supported by the fact that the Pacific *An. farauti* larvae had the ventral surface of the head—which is of course presented to the surface film in the normal feeding position—heavily infested, while the dorsal surface seldom bore algal cells. These authors also suggested that the absence of *C. anophelesi* from *Culex* larvae is perhaps due to the lesser amount of sunlight available at the surface of the body because of the head-downwards position adopted during feeding. Although *C. saccatum* is less host-specific than *C. anophelesi* it certainly shows a preference for the posterior abdominal segments—which are closer to the surface in the feeding position—of culicine larvae.

*C. anophelesi* was not regarded as pathogenic by Iyengar and Iyengar, the only effect of the presence of a growth of this alga being a slight hampering of the movements of the host. The movements of *An. farauti* and *C. annulirostris* were similarly hampered by the *Characium* under discussion, the latter mosquito sometimes indulging in twisting movements to bite at the siphon, anal segment and anal papillae as in the case of heavy ciliate infestations (p. 110). In several instances the anal papillae of *C. annulirostris* larvae of the fourth instar were somewhat shrivelled in appearance and distorted at the tip (Fig. 4) when heavily covered with algal cells. Pupation was never impeded, though, and normal imagines always emerged in due course. *Characium* cells were only rarely seen on pupae.

#### ECTOZOOA

PROTOZOA. Mastigophora. *Codonoecca* aff. *associans* (Pl. 1, Fig. 8).

Several second and third instar larvae of *Culex pullus* from a transient pool at Ilu Farm, Guadalcanal (coll. no. 272; pH 7.2 @ 25°C) bore small colonies of

Figs. 1-5.—*Characium* aff. *saccatum* Filarzsky, from *Anopheles farauti* (1, 2, 3, 5.) and *Culex annulirostris* (4) (coll. no. 30). Figs. 1 and 2.—Zoospore formation. Iron haematoxylin. 1,380 X. FIG. 3.—Basal attachment disc. From life. 1,380 X. FIG. 4.—Heavily infested anal papilla. *C. annulirostris*. Unstained 'Sirra' mount. 152 X. FIG. 5.—Habit, head of *An. farauti*. Unstained 'Sirra' mount. 152 X. FIGS. 6 and 7.—*Sphaerotilus* aff. *dichotomus* (Cohn) on tip of anal papilla of *Culex pullus* (Fig. 6; coll. no. 263) and on a caudal hair of *An. farauti* (Fig. 7; coll. no. 267). From life. 880 X. FIG. 8.—*Codonoecca* aff. *associans* from *C. pullus* (coll. no. 272). From life. 880 X.

All figures drawn with the aid of a Zeiss-Winkel drawing apparatus and—except in the case of stained material—by phase contrast microscopy. Photographs original unless otherwise acknowledged.

a flagellate at the lateral margins of the thorax. No other ectocommensals were present.

A gelatinous, granule-encrusted stalk averaging about  $6\mu$  in width and ranging up to  $35\mu$  in length stood out at right angles to the cuticle of the host (Fig. 8). No details regarding the nature of the attachment could be made out with living material, and attempts to preserve and stain the organism were unsuccessful. At the distal end of the stalk were from five to nine closely approximated monostigotes flagellates, each within an ovoidal lorica measuring a little over  $10\mu$  in length by up to  $6\mu$  in width. The body of each flagellate was broadly fusiform, and there was a posteriorly positioned contractile vacuole of about  $1\cdot1\mu$  diameter. A rather thick flagellum about  $13\mu$  long protruded from the opening of the lorica for a distance equivalent to the length of the lorica itself.

The morphology of this organism refers it to the family Bicosoecidae of the order Protonomadina as defined by Kudo (1946). It is not possible to be certain of its systematic position in the absence of stained material, but it comes close to *Godonoeca* aff. *asocians*.

I have been unable to locate any previous record of ectocommensal flagellates from mosquito larvae.

**PROTOZOA. Ciliata.** Representatives of the order Peritrichia were commonly attached to the developmental stages of numerous species of mosquitoes. They belonged to the genera *Zoothamnium*, *Vorticella* (nam. Vorticillidae Fromental) and *Epistylis* (fan. Epistyliidae Kent). All the records are noted in Table I.

Of the 372 collections which included larval mosquitoes, 213 were made from surface water (habitat categories 1-5, 9-10) while 159 were made from containers (habitat categories 6-8, 11 and 12). Larvae from 64 (17 per cent.) of the collections were infested with *Vorticella*, 58 of the collections concerned being from surface water and only six from containers. Only natural (rock holes) and artificial (drums, etc.) large simple containers were involved. Larvae from 35 habitats (15 of these negative for *Vorticella*) bore growths of *Epistylis*. This genus was only recorded once from a container (coll. no. 120, a large metal tank sunk into the ground). *Zoothamnium* was found on but a single occasion, a single dichotomous stalk bearing two individuals being attached to the abdomen of a fourth instar larva of *Culex annulirostris* from Lake Tenggano, Rennell (coll. no. 250). Eighty (22 per cent.) of the larval habitats studied thus included larvae infested with peritrichous ciliates.

*Zoothamnium* sp. This genus is recorded from a "Siria" mount of the *C. annulirostris* larva referred to above. The two zooids are contracted and distorted as is unavoidable in such mounts, and their nuclei cannot be made out by phase contrast. They were at first taken for epistylids, but a closer examination disclosed a bifurcated spasmoneine exhibiting spiral conraction within the short, thick stalk. Crustaceans are the usual hosts for *Zoothamnium*, which is comparatively rare on insects. Nenninger (1918), following the examination of 21 species of crustaceans and 58 of insects, reported that five species of the former group harboured a total of nine species and varieties of these ciliates, while only one representative of the genus was present on a single insect host, a mayfly nymph. There does not appear to be any previous record of *Zoothamnium* from the Culicidae.

*Vorticella microstoma* Ehrenberg, 1830 (Pl. 2, Figs. 11 and 13; Pl. 7, Fig. 42).

Normal trophontes of Pacific material of this vorticellid are pyriform, the body being inflated medially (Figs. 13 and 42). The fully expanded peristome is appreciably narrower than the broadest part of the body. Large examples frequently exhibit a posterior constriction at the zone of development of the posterior ciliary wreath (Fig. 13), the wreath itself only being apparent in free-swimming telotrochus and in individuals about to detach themselves from the stalk.

There is a considerable range in size, the measurements of 30 living examples from various hosts and localities being as follows.—Length,  $34\cdot1\mu$  to  $71\cdot1\mu$  (av.,

(49.2 $\mu$ ); greatest breadth, 23.0 $\mu$  to 45.3 $\mu$  (av., 32.8 $\mu$ ); breadth of peristome 11.1 $\mu$  to 27.8 $\mu$  (av., 22.2 $\mu$ ); diameter of contractile vacuole, 8.0 $\mu$  to 12.3 $\mu$  (av., 10.2 $\mu$ ); length of stalk, up to 173 $\mu$  (av., c. 80 $\mu$ ); diameter of stalk, 2.7 $\mu$  to 4.5 $\mu$  (av., 3.3 $\mu$ ); diameter of spasmoneme, 1.6 $\mu$  to 1.8 $\mu$  (av., 1.7 $\mu$ ).

Individuals having from 23 to 55 pellucidal striae were noticed, the distance between striae varying from 1.1 $\mu$  to 1.5 $\mu$  and the actual number present increasing with the size of the animal. The macronucleus is elongate and longitudinally positioned in the larger examples (Fig. 13), but it is frequently thick and U-shaped and transversely placed towards the anterior extremity in smaller ones (Fig. 11).

The contractile vacuole interval is somewhat variable, but is usually within the limits of 9 to 16 seconds in vorticellids freshly placed on the microscope stage using as little light as possible in order to reduce the adverse effects of light and heat. Successive intervals (in seconds) for three such individuals were, 11.0, 10, 10, 11, 10; 14, 14, 16, 14, 15; 12, 10, 11, 9, 12. Another example which was subjected to the maximum light and heat of the microscope's integral illuminator exhibited successive intervals of 10, 10, 11, 16, 20, 21 and 31 seconds. Intervals were also noted for two recent products of ordinary vegetative division. The daughter individual had a completely formed posterior ciliary wreath and had commenced to feed, but cleavage had not yet taken place; successive contractile vacuole intervals for the parent were 16, 14, 15, 15 and 13 seconds and for the daughter 16, 15, 16, 14 and 16 seconds.

Many of the examples studied, notably those on very young larvae, had short stalks, often shorter than the body itself. These were otherwise morphologically similar to long-stalked individuals, and had obviously only recently attached themselves to the host. The length of the spasmoneme spiral is in the vicinity of 30 $\mu$  in those vorticellids having a stalk of average length, three spirals characteristically being present. The stalk itself exhibits a slight but appreciable sinuosity. Although phase contrast microscopy affords an ideal means of the demonstration of the copiastic granules in the stalk of living vorticellids, such granules were never observed although they were carefully searched for. They are thus considered to be lacking.

Finally, the ratio of length to breadth is usually in the vicinity of 1.5 to 1, but in actively feeding individuals, which may appear almost globular, it may fall to 1.1 to 1 (Fig. 42). Certain of the smaller specimens seem exhibited practically no inflation of the median zone of the body, the breadth of the peristome being about the same as, or even exceeding (Fig. 11), that of the body proper at its greatest diameter. The macronucleus of such vorticellids was practically always anterior in position and transversely placed. The animals in question were always associated with others exhibiting the characters of the species under discussion.

With the exception of the small forms having a relatively broad peristome just referred to, the species described herein answers closely to *V. microstoma* Ehreberg as redescribed by Noland and Finley (1931). Its average size and maximum dimensions are somewhat less than in the material before these authors, who recorded the length as 35 $\mu$  to 83 $\mu$  (mode, 53 $\mu$ ) and the breadth as 22 $\mu$  to 30 $\mu$  (mode, 35 $\mu$ ), and the stalk never reaches the length of 385 $\mu$  sometimes attained by their American strain. A probable reason for this is the nature of the substratum. Noland and Finley were dealing with specimens growing in laboratory infusions which would not have to face the mechanical problems associated with uncoiling and retraction from a constantly and erratically moving aquatic insect. Too great a stalk length would surely be of material disadvantage to vorticellids utilizing such a habitat. Bary (1950) based his identification of *V. microstoma* from New Zealand on comparisons with the data presented by Noland and Finley, but gave no measurements from his own specimens. His Pl. 39, Fig. 16 shows an example of similar morphology to that illustrated in Fig. 13 herein, but of considerably larger size—93 $\mu$  by 63 $\mu$ , according to his scale line. Bhatia (1936) gave 100 $\mu$  as the maximum length attained by the species in India. Stout (1951) also discussed a New Zealand strain of *V.*

*microstoma*, his trophozoites being of the order of size of those of Noland and Finley. The macronucleus of the normal form is illustrated as sausage-shaped and transversely positioned in Stout's Text-fig. 2, 1.

Noland and Finley (1931) also dealt with a smaller vorticellid measuring from  $23\mu$  to  $53\mu$  (mode,  $35\mu$ ) by from  $15\mu$  to  $32\mu$  (mode,  $19\mu$ ) and having a relatively broader peristome ranging from  $13\mu$  to  $26\mu$  in breadth (mode,  $18\mu$ ). They pointed out that this animal has a short, thick macronucleus transversely placed in the upper part of the body, and has more clearly marked pellicular striae and less toleration to laboratory infusions than has *V. microstoma*. In other respects it resembles "a small edition of the latter." These authors designated the smaller organism *Vorticella striata* var. *octava* (Stokes), despite the fact that Dujardin had originally described *V. striata* from sea water.

Most of the present material is recorded from mosquito larvae from obviously polluted water (p. 107), which is in accord with observations from Malaya to the effect that anopheline larvae are rarely if ever heavily infested with vorticellids except in relatively impure water (Williamson, 1935). Both the individuals having a longitudinally positioned macronucleus and those with a transverse one occur without reference to the degree of pollution. Stout's (1951) specimens exhibiting a transversely placed macronucleus were from the highly organic fluid of a meat digestion plant. The pellicular striae were usually well marked in the Pacific material, as they also were in the examples figured by Bary (1950) and Stout. The latter author made the interesting observation that starved and recently excysted specimens of *V. microstoma* are small and relatively thin ( $40\mu$  by  $20\mu$ ), the peristome in such cases being much broader than usual in relation to the breadth of the body proper. His Text-fig. 2, 3 illustrates a recently excysted form of very similar proportions to that seen in Fig. 11 of this paper.

In view of these facts, and the admission of Noland and Finley themselves that specimens occur which are almost intergrades between *V. microstoma* and the smaller form to which they gave the name of *V. striata* var. *octava*, and, as the size ranges of the two forms as understood by these authors overlap appreciably, there is hardly justification for the designation of two species on morphological grounds. As to the matter of physiological differentiation, it is surely more reasonable to recognize the occurrence of biological strains within the one freshwater species *V. microstoma* than to assign the atypical small forms under consideration to a marine species, *V. striata*. If a varietal name must be applied to the smaller form—and such a procedure could lead to endless "splitting" within such patently polymorphic species as *V. microstoma*—*V. microstoma* var. *abbreviata* Keiser (1921) antedates the papers of Noland and Finley.

*V. microstoma* was recorded from all but three of the collecting stations—coll. nos. 255, 267 and 276—indicated as positive for *Vorticella* in Table I, and in all cases was the only vorticellid present on the infested larvae. The mosquito species from which this ciliate was recorded are listed below in order of the frequency with which infestations were noted. The number following each specific name is the number of infested collections, while the bracketed percentages indicate the percentage of the total number of collections of each of the mosquitoes so infested.

<i>Culex annulirostris</i>	.....	.....	35	(29 per cent.)
<i>Anopheles farauti</i>	.....	.....	14	(24 " "
<i>Culex fraudatrix</i>	.....	.....	6	(29 " "
<i>Anopheles annulipes</i>	.....	.....	4	(17 " "
<i>Culex pipiens fatigans</i>	.....	.....	4	(15 " "
<i>Culex pullus</i>	.....	.....	4	(33 " "
<i>Anopheles punctulatus</i>	.....	.....	3	(20 " "
<i>Uranotaenia civinskii</i>	.....	.....	3	(33 " "
<i>Uranotaenia solomonis</i>	.....	.....	3	(100 " "
<i>Culex halifaxi</i>	.....	.....	3	(25 " "

<i>Aedes lineatus</i>	...	...	2	(22	"	"	)
<i>Aedes vexans nocturnus</i>	...	...	2	(13	"	"	)
<i>Aedes vigilax</i>	...	...	2	(25	"	"	)
<i>Culex mimulus</i>	...	...	2	(67	"	"	)
<i>Bironella hollandi</i>	...	...	1	(25	"	"	)
<i>Culex basicinctus</i>	...	...	1	(11	"	"	)

Collections positive for *V. microstoma* were made from habitats the hydrogen ion content of which ranged from pH 6.0 to pH 9.5, almost half of these falling within the range pH 7.2-7.4. The outstandingly significant correlation between the occurrence of infestations and a habitat factor was, however, that with pollution by animals. Of the 61 collections in which the ciliate figured, 57 (93 per cent.) were from habitats in which such pollution (usually by the dejecta of domestic animals, notably pigs, cattle and horses) was patent. The water in three of the other habitats (coll. nos. 6, 17, 18) was clean and odorless, while that in the remaining one (coll. no. 36) contained decomposing leaves but was out of the reach of any of the vertebrates which occurred locally. Larvae from the 106 other stations listed as polluted in Table I were negative for *Vorticella*. Thirty-six of these (from 14 of which larvae bearing other peritrichous ciliates were collected) showed signs of pollution by animals, while in 70 of them (39 in this group being either simple or specialized containers) the only source of pollution was vegetable decomposition. Thus 57 (61 per cent.) of the 93 mosquito larval collections from habitats polluted by animals included larvae infested with *V. microstoma*, while only one (1.5 per cent.) of the 70 such collections from habitats polluted only by decomposing vegetation was positive for this ciliate.

These facts are in accord with the known habits of *V. microstoma*, which according to authorities quoted by Stout (1951) is one of the most common sewage Protozoa. They have a direct bearing on the host occurrence of the ciliate, all but one of the mosquitoes from which it was recorded characteristically utilizing standing surface water subject to animal pollution as larval habitats. The only occasion upon which *V. microstoma* was noted on a larva typically occurring amongst green algae in clean, flowing water was when a few trophozoites were observed on two of 28 *C. basicinctus* larvae closely associated with heavily infested *C. annulirostris* in a ponded ditch bordering a cattle paddock near Luganville, Espiritu Santo (coll. no. 31).

The degree of infestation was observed to vary with the age of the larva, third and fourth instars generally speaking being more thickly covered with vorticellids than first and second instars. This does not reflect steadily increasing ciliate populations, for the vorticellids are thrown off with each moulted skin. It is a factor of the greater surface area open to ectozoan invasion in the case of older larvae, combined with the fact that at each moult some at least of the protozoans from the old skin leave their stalks and at once re-attach themselves to the host. Although pupae were often infested, these seldom bore more than a few scattered ciliates. In 14 collecting stations supporting more than one species of mosquito, each species present was positive for *V. microstoma*, while in 16 other such stations one or more of the species present was negative for this ciliate. Sometimes there was no obvious explanation for this—thus two closely adjacent transient pools at Aore, New Hebrides, held larvae of both *An. farauti* and *C. annulirostris*; in one of them (coll. no. 10) only the latter species bore vorticellids, in the other (coll. no. 11) only *An. farauti* was infested. In other cases the explanation probably lies in differing larval habits. Thus the infested *C. annulirostris* larvae from coll. no. 46 kept together near the cattle-trampled margin of a ponded ditch, while the non-infested *C. bitaeniorthynchus* larvae were only to be found in masses of *Spirogyra* where the localized high oxygen level resulting from photosynthesis might have exercised a repellent effect upon the bacteria-feeding *V. microstoma*.

Only eight (14 per cent.) of the 57 infested collections from animal-polluted habitats were from brackish water, the number of ciliates present being few in all cases, and eight (21 per cent.) of the 36 animal-polluted but *Vorticella*-free habitats were brackish. Although *V. microstoma* was thus present in half of the brackish and animal-polluted habitats, the lightness of the infections suggests that a degree of salinity is unfavourable to this protozoan.

Infested larvae generally bear the heaviest concentrations of ciliates on and about the anal papillae and at the intersegmental grooves of the abdomen. The thorax is sometimes involved also, but the head rarely bears any vorticellids. Infestations were classed as heavy when larvae bore masses of *V. microstoma* as in Fig. 42 (as many as 1,500 individuals have been counted on a single larva), as medium when numerous ciliates were present although not packed together in dense concentrations, and as light when only a few scattered examples were evident. While animal pollution is the significant factor as regards the occurrence and non-occurrence of *V. microstoma* on its mosquito hosts in the South Pacific, the hydrogen ion content of the water has bearing on the degree of infestation. Twenty of the freshwater habitats concerned were classed as exhibiting heavy infestation, seven as exhibiting medium infestation and 26 as exhibiting light infestation. Within each of these groups the numbers of occurrences of *V. microstoma* for each pH value were as follows:-

TABLE XIX  
Correlation of *Vorticella microstoma* infestation with pH.

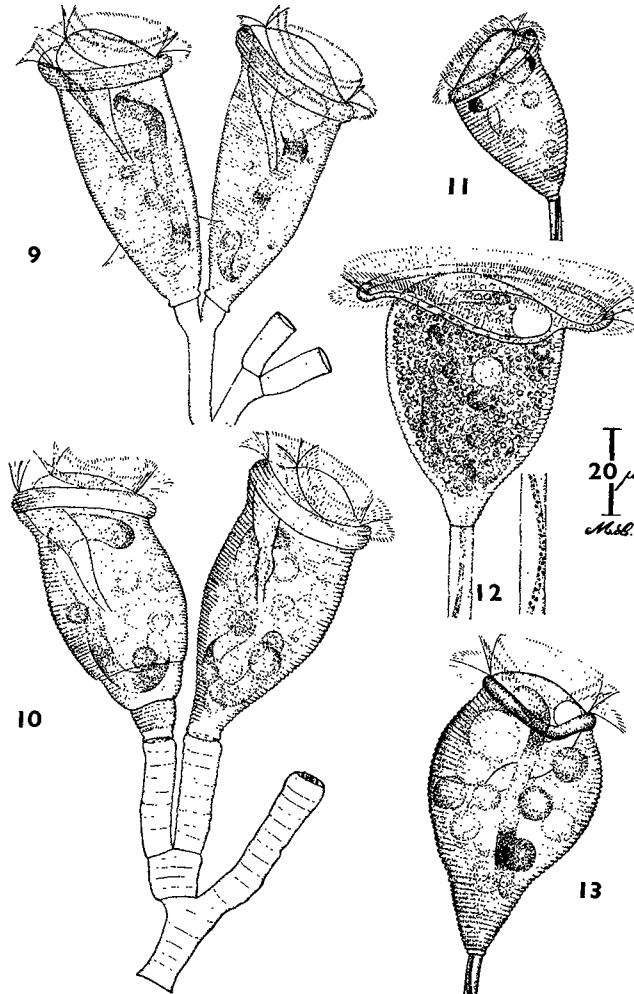
pH value	6.0	6.2	6.1	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6+
Heavy infestation	—	—	—	1	—	1	5	11	1	—	1	—	—	—
Medium infestation	—	—	—	—	1	2	1	2	—	—	1	—	—	—
Light infestation	3	3	—	2	3	2	3	3	—	1	1	2	2	1
Totals	3	3	—	3	4	5	9	16	1	1	3	2	2	1

Thus, while infested collections were made from waters of pH 6.0-8.6+ (9.5), 16 (30 per cent.) of the heavy infestations and 25 (17 per cent.) of all the relevant collections were from habitats of pH 7.2 or pH 7.1. It is therefore apparent that although *V. microstoma* occurs through quite a wide range of acid and alkaline waters, it flourishes best under conditions of slight alkalinity.

It is concluded that non-saline waters of high nitrogenous content and exhibiting slight alkalinity afford the optimum conditions for the development of *V. microstoma* on mosquito larvae. Larval habitats answering to this description were not encountered on Bellona, Sikaiana, Savai'i, Nukunono, Tarawa or Funafuti, and only one such habitat (coll. no. 83) was seen on Futuna. These are the only islands from which reasonable numbers of larval collections were made where vorticellids were not recorded.

As to the preference exhibited by the ciliate for the anal papillae and their vicinity, it is suggested that as vorticellids are typically bacterial feeders (Sandon, 1932) this may well be due to a greater availability of bacteria about the posterior extremity of the body in consequence of larval defaecation. The influence of the constant uptake of water and chloride ions by the papillae themselves (Wigglesworth, 1938) may also have bearing on the problem, and although the weight of evidence is not in favour of the thesis that these papillae have any respiratory function even a small amount of oxygen diffusion taking place across their membranes could in itself account for the local concentration of both bacteria and such a facultative anaerobe as *V. microstoma* (Engelmann, 1895). It is of significance in this connection that mosquito pupae, which neither feed nor have anal papillae, never bear more than a few scattered vorticellids.

Mosquito larvae heavily infested with *V. microstoma* were often observed to be suffering considerable inconvenience thereby. They frequently arched themselves



Figs. 9 and 10.—*Epitylium lacustris* Imhoff from *C. annulirostris*. FIG. 9.—Coll. no. 30. FIG. 10.—Coll. no. 201. From life. 880 X. FIG. 11.—*Vorticella microstoma* Ehrenberg from *An. farauti* (coll. no. 265). From life. 880 X. FIG. 12.—*V. complanata* Ehrenberg from *C. halifaxi* (coll. no. 255) with detail of median portion of stalk. From life. 880 X. FIG. 13.—*V. microstoma* Ehrenberg from *C. halifaxi* (coll. no. 262). From life. 880 X.

so as to bring the mouthparts in contact with the posterior extremity of the body, meanwhile sinking slowly to the bottom of the habitat or laboratory observation jar. An *An. farauti* larva which had been behaving in this manner was dissected, and some vorticellids still displaying feeble movement were demonstrated in its gut contents. Heavily infested anal papillae are apt to appear withered and somewhat darkened, particularly at the tips (e.g., *A. vexans nocturnus*, coll. no. 114). This was the only pathological condition noted, and no matter how heavy the infestation pupation always took place and healthy imagines emerged in due course.

*Vorticella campanula* Ehrenberg, 1831 (Pl. 2, Fig. 12).

This species was found twice only, on both occasions in drums of rainwater at Ilu Farm, Guadalcanal (coll. nos. 255 and 276). The mosquito hosts were *Culex annulirostris*, *C. halifaxi*, *C. pullus* and *C. pipiens fatigans*. A few first and second instar larvae of *Anopheles farauti* in the second drum were not infested.

All the following observations were made from life by phase contrast microscopy. The body is bell-shaped, the expanded peristome being appreciably broader than the body proper. The cytoplasm contains a mass of refractile spherules (interpreted by Noland and Finley, 1931, as reserve granules) through which the elongate nucleus, which runs transversely just beneath the peristome disc and then longitudinally almost to the posterior extremity, can only be made out with difficulty (Fig. 12). The contractile vacuole interval is shorter than in the preceding species, ranging from five to nine seconds (av., seven seconds) in my material. Tiny thecoplastic granules are evident along the spasmoneme of the stalk. Twenty individuals were measured, their dimensions being as follows.—Length,  $60\cdot2\mu$  to  $79\cdot7\mu$  (av.,  $69\cdot7\mu$ ); breadth,  $30\cdot0\mu$  to  $49\cdot1\mu$  (av.,  $38\cdot5\mu$ ); breadth of peristome,  $50\cdot0\mu$  to  $61\cdot3\mu$  (av.,  $56\cdot7\mu$ ); diameter of contractile vacuole,  $6\cdot1\mu$  to  $9\cdot1\mu$  (av.,  $7\cdot9\mu$ ); length of stalk, up to  $180\mu$  (av., c. $120\mu$ ); diameter of stalk,  $5\cdot4\mu$  to  $7\cdot8\mu$  (av.,  $6\cdot2\mu$ ); diameter of spasmoneme, c. $2\cdot0\mu$ .

The pellicular striae are fainter than in *V. microstoma*, but show up quite well by phase contrast none the less. Up to 60 were counted, the distance between them varying from  $0\cdot9\mu$  to  $1\cdot3\mu$ . The animal is of rather opaque appearance. It exhibits characteristic bending movements about the point of attachment to the stalk, and does not undergo retraction nearly as quickly or as readily as does *V. microstoma*. Most of the infestations observed were light to medium ones, and even in quite heavy ones there was no particular concentration about the anal papillae, the ciliates being scattered all over the thorax and abdomen.

*V. campanula* was redescribed by Noland and Finley (1931). The cultures studied by these authors included individuals which attained a greater size (up to  $157\mu$  by  $99\mu$ ) than did those from Guadalcanal. The latter ciliates also differed from the former in having a relatively narrower body, the ratio of length to breadth for average specimens being 1.8 to 1 as compared with the 1.2 to 1 deduced from the figures of Noland and Finley. This is perhaps due to starvation or to a difference in techniques, my measurements being taken from enlarged photomicrographs of fully extended trophic individuals. The example illustrated in Fig. 12 compares more closely with those of the American authors, and was drawn by means of the Zeiss Winkel drawing apparatus from a preparation which had been on the microscope stage for some time and in which the vorticellids had retracted to some extent and had become quite sluggish. Noland and Finley gave the average length of the stalk as  $300\mu$  (range,  $50\mu$  to  $4,150\mu$ ), but it is hardly to be expected that individuals attached to active larvae would develop stalks of such length. These authors stated that the spasmoneme spiral averages  $75\mu$  in length (range,  $53\mu$  to  $110\mu$ ). In my examples this spiral was always close to  $40\mu$  in length, but the relative shortness apparent here is probably correlated with that of the stalk itself. The thecoplastic granules are arranged in a band along the spasmoneme just as described by Noland

and Finley. As to the habitat, these authors noted that *V. campanula* avoids particularly places where the water is foul from decomposition.

The vorticellid under discussion compares more closely with *V. campanula* than with any other of the comparatively few species of the genus of which adequate descriptions have been published. It is felt that the similarities between it and the material studied by Noland and Finley so far outweigh the differences as to render any other course than its identification with this species inadmissible.

*Vorticella* sp.

One fourth instar larva of *Anopheles farauti* which was collected from practically pure sea water at the edge of a tidal inlet in Guadalcanal (coll. no. 267) proved to have a single example of a species of *Vorticella* attached to the groove between two of its abdominal segments.

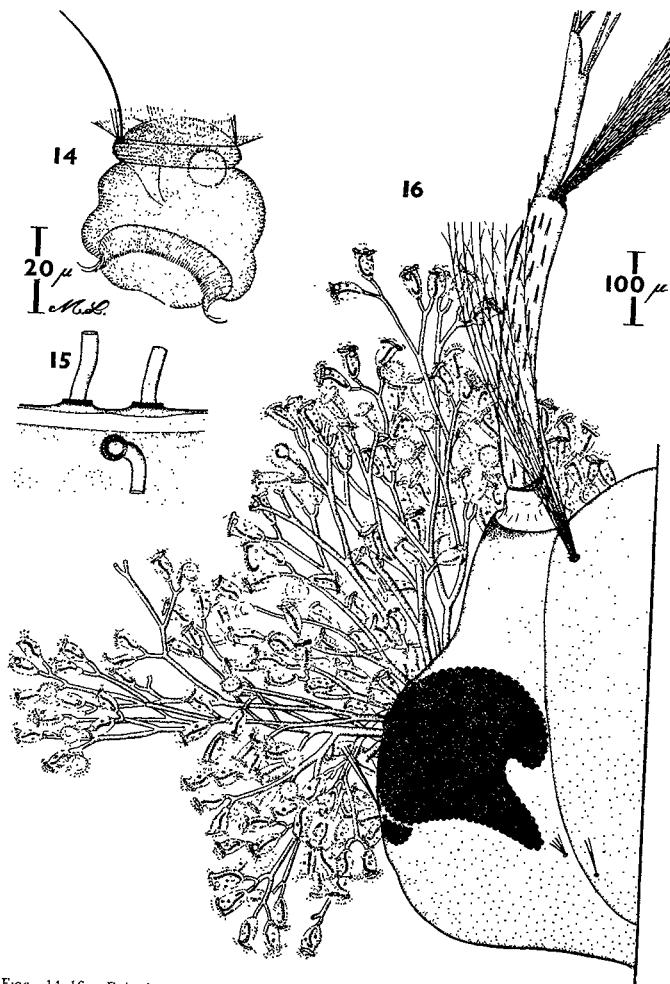
This ciliate resembled *V. campanula* in being bell-shaped and in its readiness to bend the body about the point of attachment to the stalk. It differed from the latter species in having a relatively narrower peristome and in that thecoplastic granules were completely lacking. The animal measured  $50\mu$  by  $50\mu$ , the peristome being  $51.7\mu$  in breadth. There was a single contractile vacuole, the interval of which was not noted, and the form of the macronucleus was not determined. The stalk was  $99\mu$  in length and  $4.6\mu$  in breadth. Nothing can be done with such limited data beyond merely noting the occurrence of a *Vorticella* differing in morphology and habit from the two species already considered in detail.

*Epistylis lacustris* Imhoff, 1884 (Pl. 2, Figs. 9 and 10; Pl. 3, Figs. 14-16).

Larvae from 35 of the collecting stations were infested with non-loricate peritrichous ciliates the adoral zone of which described little more than one complete circuit of the peristome, and which formed colonies on a dichotomously branched non-contractile stalk lacking a spasmodeme. These features refer the organisms to the genus *Epistylis* Ehrenberg, the same species being concerned in all cases.

The following description is based on specimens from *Culex annulirostris* from the Gateville Plantation, Aore, New Hebrides (coll. no. 9). It is amplified by notes on further material from various hosts and localities.

Fifty trophic individuals in a freshly mounted preparation gave these measurements—Length,  $53.2\mu$  to  $73.4\mu$  (av.,  $61.4\mu$ ); greatest breadth,  $20.1\mu$  to  $34.8\mu$  (av.,  $26.8\mu$ ); diameter of contractile vacuole,  $8.3\mu$  to  $9.1\mu$  (av.,  $8.8\mu$ ). The elongate nucleus runs transversely beneath the peristome then follows a longitudinal course towards the posterior extremity and curves anteriorly for a short distance once more. There are up to 80 peculiar striae, the distance between which varies from  $0.6\mu$  to  $1.1\mu$ . Fully extended trophozoites are elongate, the ratio of length to breadth usually being in the vicinity of 2.4 to 1. The peristome disc is raised up into the form of a dome, and the peristome itself is as broad as, or rather broader than, the body proper. There is a well marked scopula, which is sometimes slightly dilated (Fig. 9), at the posterior extremity. Partly contracted examples (left hand example, Fig. 10) exhibit a degree of plication posteriorly, while under the continued influence of the heat and light of the microscope illuminant the animal adopts the fully contracted position in which the ratio of length to breadth falls to about 1.5 to 1 (range, 1.2 to 1 to 1.7 to 1). The non-contractile stalk is hyaline and is generally non-septate, although in older colonies septa may be formed, particularly at the point of origin of the ultimate branches (Fig. 9). The blindly ending stalks from which telotrochs have swum away may appear hollow (Fig. 9) or may be closed over by a septum which is somewhat tuberculate (Fig. 10). Both conditions may be apparent in a single colony. The surface of the stalk is smooth in the case of recently attached individuals and young colonies, but may become rather wrinkled and exhibit transverse striations in older ones (Fig. 10). There is a narrow, ring-like holdfast at the point of attachment to the host (Fig. 15), and the underlying host cuticle is sometimes thickened and slightly drawn upwards. The pairs of ciliates at the



Figs. 14-16.—*Epiplax lacustris* Inhoff from *C. annulirostris*. FIG. 14.—Telocephal (coll. no. 201). From life. 380 X. FIG. 15.—Holdfast on an anal papilla (coll. no. 31). Unstained "Sua" mount. 680 X. FIG. 16.—Habit study from a heavy infestation (coll. no. 292). Unstained "Sua" mount. 152 X.

ends of the branches retract independently of one another (Fig. 10), and the con tractile vacuole interval is usually between 10 and 12 seconds.

Telotroch formation takes place readily on the microscope stage, a posterior ciliary wreath being formed very quickly (left hand example, Fig. 9). Free swimming telotrochs often exhibit a slight invagination posteriorly where the attachment to the stalk formerly took place, and under the artificial conditions of the microscope stage they may become detached from the stalk with the peristome still partly expanded (Fig. 14). A long and conspicuous frontal cirrus is formed at this time (Fig. 14). Kahl (1935) referred to this organelle as the "Epistomiflamme," and figured it for the telotrochs of *Epitylis fluitans* (Fauré-Fremiet) (his Fig. 130, 14), *Rhabdotyla inclinans* (Penard) (his Fig. 129, 2) and *R. sessilis* (Penard) (his Fig. 129, 4). The function of the frontal cirrus appears to be a locomotory one.

Colonies of from four to 20 individuals were present in the Aore material, the length of the stalk ranging from 20 $\mu$  in the case of the more recently attached ciliates up to 130 $\mu$  in older colonies and the breadth averaging about 5.5 $\mu$ . The morphology of specimens seen subsequently in other localities on the same and other hosts answered to the above description, but a much greater range in the size of the colonies became evident. Thus some very recently attached examples from *Uranotaenia ciuinskii* (coll. no. 260, Guadalcanal) had not yet developed any sign of a stalk, while others on the same host and on *G. annulirostris* from various localities had stalks measuring up to only 8 $\mu$  in length by 3.5 $\mu$  to 6.5 $\mu$  in breadth. These recently attached individuals naturally occurred singly and would have had to be referred to *Rhabdotyla* Kent had they not been associated with morphologically identical ciliates on slightly longer but dichotomously branched stalks. Very large colonies, such as those on the head of a fourth instar larva of *C. annulirostris* from Tonga (coll. no. 292) illustrated in Fig. 16, were as much as 550 $\mu$  in height, the proximal part of the stalk attaining a breadth of up to 14 $\mu$  and the holdfast being up to 30 $\mu$  in diameter. Colonies of this size included up to 46 individuals.

A formidable number of species of *Epitylis* have been described, many of them so inadequately that it is quite out of the question to assign material from new localities and hosts to them. From the investigations of Kahl (1935), Precht (1935) and Nemninger (1918), who have given accounts of the European species, it would appear that overall size, the ratio of length to breadth, the form and location of the macronucleus, the number of individuals per colony and the morphology of the stalk have been relied upon as specific criteria. Members of the genus are characteristically found attached to freshwater or marine animals, such associations being much more marked than is the case with *Vorticella*, and considerable importance has also been attached to host specificity.

Overall size and the ratio of length to breadth may vary from locality to locality and also according to the techniques employed in study, while arbitrary descriptions of new species from limited material can easily lead to a species being considered never to form more than four or eight individuals per colony when much larger colonies might be disclosed from the examination of a wider range of material. Even the morphology of the stalk is subject to considerable variation as is seen in the case of the present species, and Saville-Kent (1880-82) quoted Stein as remarking that the stalk of *E. plicatilis* Ehrenberg, which normally is non-septate, is pointed in old specimens. The form and location of the macronucleus were constant throughout my material, and these features appear to be of greater taxonomic value in *Epitylis* than in *Vorticella*.

Two species of *Epitylis* have been reported from the Culicidae. Kahl (1935) mentioned the occurrence of *E. umbilicata* Claparède and Lachmann on mosquito larvae, while Nemninger (1918) described *E. anophelis* Nemninger from larvae of *Anopheles* sp. These two European species both differ radically from the one under consideration, the former in being broadest posteriorly and tapering to a relatively

narrow peristome the disc of which has a distinctive navel-like ornamentation, and the latter in having a precisely similar peristome structure and a small, anterior C-shaped macronucleus. From the available data it appears most likely that *E. anophelis* ( $83\cdot4\mu$ ) should fall as a synonym of *E. umbilicata* ( $50\mu$ ), the very distinctive structure of the peristome surely being of much greater taxonomic significance than a relatively slight difference in size.

*E. fluitans* Fauné-Fremiet, a much larger species than the present one ( $160\mu$  in length according to Kahl, 1935) is of very similar morphology except in that its pellicle is not striated. *E. fluitans* var. *insidens* was described from chironomid larvae (Tendipedidae) by Nemninger (1918). This variety is not very much longer than the one from the Pacific ( $85\cdot4\mu$  to  $97\cdot6\mu$ ) but resembles the typical form in having a smooth pellicle. *E. lacustris* Imhoff was redescribed from *Cyclops* by Kahl (1935). According to this author the species is characterized by a cylindro-elongate body shaped as described herein and ranging from  $50\mu$  to  $70\mu$  in length. The ratio of length to breadth as derived from Kahl's figures (with the exception of that of the elongate form *dubia* which, being obliquely truncate anteriorly and having quite a different method of branching, should probably be referred to another species) varies from 2.2 to 1 to 2.5 to 1. The type of branching is variable, but constant in each locality, the ultimate dichotomies sometimes being short as in Kahl's form *dichotoma* (Fig. 9) or quite long as in his form *typica* (Figs. 10, 16). Sometimes the species occurs as single trophozoites having a short, broad stalk (form *shadostyloides*) or in groups of two individuals only (form *dichotoma*), while fully developed colonies (form *typica*) have long stalks and include from eight to 16 individuals. In some long-stalked colonies the stalk itself is rather wrinkled and transversely striated (form *rugosa*). One of Kahl's illustrations (his Fig. 13a, 13) portrays a partly retracted example exhibiting puckering posteriorly (cf. left hand example, Fig. 10 herein), while ciliates proceeding to the telotroch stage exhibit a deep invagination at the point of attachment to the stalk (Kahl's Figs. 13a, 10, 13) just as did those studied in the Pacific. The striation of the pellicle and the form and location of the macronucleus are as described herein.

Finally, Kahl (1935) pointed out that *E. lacustris*, which is of common occurrence near Hamburg, is found in somewhat polluted "subsapropelen" waters. With but two exceptions my collections were made from animal-polluted habitats (p. 115). Although *E. lacustris* was described from *Cyclops*, Nemninger (1918) described a large form of this species (var. *magna*) from mayfly nymphs. The lack of time unfortunately prevented the study of ectocommensal ciliates of animals other than mosquitoes while in the field during this project, but on one occasion (coll. no. 302) groups of two and four epistylids in every way comparable with those under discussion were noted on the copepod *Cryptocyclops bicolor linjanticus* (Kiefer).

On the basis of these data the ciliate under consideration is identified as *Epistylis lacustris* Imhoff as redescribed by Kahl (1935). The occurrence of more extensive colonies than those described for this species hitherto is attributed to the greater possibilities for increase in size when the substratum is the cuticle of a very much larger animal than a cyclopoid.

All the *Epistylis* collection records in Table I refer to *E. lacustris*. Although this ciliate was not so frequently noted as *V. microstoma* its range duplicated that of the latter species except in that it was not collected on Uvea. The mosquito hosts are listed below in the order of the frequency with which infestations were noted. The number following each specific name is the number of infested collections, the bracketed percentages indicating the percentage of the total number of collections of each of the mosquitoes so infested.

<i>Culex annulirostris</i>	—	—	—	19	(16 per cent.)
<i>Anopheles annulipes</i>	—	—	—	4	(17 " "
<i>Anopheles farauti</i>	—	—	—	4	(7 " "
<i>Uranotaenia cinctifrons</i>	—	—	—	3	(33 " "

<i>Aedes lineatus</i>	...	...	...	...	3	(33	"	"	)
<i>Culex fraudatrix</i>	...	...	...	...	3	(14	"	"	)
<i>Culex pullus</i>	...	...	...	...	3	(25	"	"	)
<i>An. b. bancroftii</i>	...	...	...	...	2	(25	"	"	)
<i>Uranotaenia solomonis</i>	...	...	...	...	2	(67	"	"	)
<i>Aedes vexans nocturnus</i>	...	...	...	...	2	(13	"	"	)
<i>Culex pipiens fatigans</i>	...	...	...	...	2	(7	"	"	)
<i>Bironella hollandi</i>	...	...	...	...	1	(25	"	"	)
<i>Aedes vigilax</i>	...	...	...	...	1	(13	"	"	)

The correlation of the collection records with animal pollution paralleled that for *V. microstoma*. Only two habitats from which *E. lacustris* was collected (coll. nos. 192 and 195) held water that appeared clean, both of these being transient pools, while 33 (91 per cent.) of the 35 water bodies concerned showed signs of pollution by domestic animals. Brackish water is even less attractive to this species than to *V. microstoma*, only one infestation (coll. no. 69), and that a very light one, being recorded.

Colonies were seen attached to all parts of the body of mosquito larvae including the siphon and anal papillae, but the heaviest concentrations always occurred on the ventro-lateral margins of the head (Fig. 16) and thorax. Thus in the case of one of the heaviest infestations noted (on a fourth instar larva of *C. annulirostris* from Tonga, coll. no. 292) 676 epistylids were counted, 43 (6 per cent.) being attached to the abdomen, 78 (12 per cent.) to the thorax and 555 (82 per cent.) to the head. In some instances even the antennae and mouth brushes bore epistylids, which were seen to feed on small organic particles swept to them in the larval feeding vortex. Sixteen of the freshwater habitats concerned are classed as exhibiting heavy infestation, eight as exhibiting medium infestation and 11 as exhibiting light infestation. The criteria for the degree of infestation are as for *V. microstoma*. Within each group the incidence of *E. lacustris* for each pH value is as follows:—

TABLE XX  
Correlation of *Epistylis* infestations with pH.

pH value	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6+
Heavy infestation	—	—	—	1	3	—	4	1	—	—	1	1	2	—
Medium infestation	—	—	—	—	1	1	3	1	2	—	—	—	—	—
Light infestation	—	2	1	—	—	—	—	2	2	—	—	2	1	—
Totals	—	2	1	—	2	4	3	7	8	—	3	2	2	1

It is apparent from Table XX that this ciliate, like *V. microstoma*, occurs through quite a wide pH range but flourishes best in waters near to neutrality. Thus 12 of the 16 habitats from which heavy infestations were recorded, and all eight of those which yielded no infestations that could be classed above medium, held water of from pH 6.6-7.4. The similar habitat preferences of the two species are underlined by the facts that all 20 stations exhibiting double infestations were animal-polluted freshwater ponds, and that 16 of these 20 (including all but one of the 12 classed as heavy for both ciliates) were from waters within the range pH 6.6-7.4.

Larvae bearing such extensive growths of *E. lacustris* as the one illustrated in Fig. 16 are obviously hindered in their movements thereby. The concentration of the ciliates about the head and thorax, which presents a striking difference from the behaviour of *V. microstoma*, is probably partly bound up with the fact that these more heavily chitinized parts of the larval body serve as a better anchorage for the holdfast, which in the case of large colonies has to withstand infinitely greater stresses than does the tiny and inconspicuous holdfast of the last-named species—and partly with the fact that *E. lacustris* ingests relatively larger food particles. Perhaps the factor of competition for available food enters into the relationship of this epistylid with the host, which may already be so hampered in its

"in the gills and the posterior segments were packed in solid masses completely filling these parts" (Keilin, 1921).

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*An. hyrcanus* var. *nigerrimus*, *An. subpictus*, *An. aconitus*,  
*An. varuna*, *An. ramsayi*, *An. annularis* and *An. jamesi*.
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*An. annularis* and *An. varuna*.

<i>Aedes lineatus</i>	...	...	...	...	3	(33	"	"	)
<i>Culex fraudatrix</i>	...	...	...	...	3	(14	"	"	)
<i>Culex pullus</i>	...	...	...	...	3	(25	"	"	)
<i>An. b. bancroftii</i>	...	...	...	...	2	(25	"	"	)
<i>Uranotaenia solomonis</i>	...	...	...	...	2	(67	"	"	)
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Medium infestation	...	...	...	1	1	3	1	2	—	—	—	—	—	—
Light infestation	...	2	1	—	—	—	2	2	—	—	2	1	—	1
Totals	...	2	1	—	2	4	3	7	8	—	—	3	2	2

It is apparent from Table XX that this ciliate, like *V. microstoma*, occurs through quite a wide pH range but flourishes best in waters near to neutrality. Thus 12 of the 16 habitats from which heavy infestations were recorded, and all eight of those which yielded no infestations that could be classed above medium, held water of from pH 6.6-7.4. The similar habitat preferences of the two species are underlined by the facts that all 20 stations exhibiting double infestations were animal-polluted freshwater ponds, and that 16 of these 20 (including all but one of the 12 classed as heavy for both ciliates) were from waters within the range pH 6.6-7.4.

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movements as to be unable to exploit its feeding grounds to the full. Larvae rendered sluggish and wasted from one or both of these causes were sometimes collected in the field, and these usually died without pupating. Nevertheless, a high percentage of larvae from every collection pupated normally. The epistyliid stalks of course remain attached to the larval inmost, the ciliates themselves soon becoming detached as free-swimming telotrochs. From time to time a few individuals at the *rhabdostyloides* and *dichotoma* stages were observed attached to pupae, but the larger branched colonies were found on larvae only.

**PREVIOUS RECORDS OF PERITRICHA FROM MOSQUITOES:** Many authors have recorded their finding ectocommensals ciliates on mosquitoes, but few have identified the species or even the genera concerned. Ehrenberg (1830, 1832) seems to have been the first to notice *Vorticella* on larvae, reporting his *V. microstoma* from *Culex p. pipiens* L. in Berlin. Speer (1927) noted the pertinent references up to that date. More recent observations include those of von Jettmar (1947) who found an undetermined vorticellid on *Culex pipiens fatigans* larvae in China and Micks (1950) who reported *V. microstoma* (which he identified specifically without publishing any relevant morphological data) from *Anopheles quadrimaculatus* Say in America. Jenkins and Knight (1950, 1952) observed undetermined *Vorticella*-like ciliates

to be particularly abundant on various species of *Aedes* in discoloured woodland pools and shaded sedge swamps in northern Canada, while Frohne (1953) noted "green peritrichous ciliates" on *Culicita* larvae in a wide variety of ground pools in Alaska. It is impossible to tell whether records such as these refer to *Vorticella*, *Epistylis* or perhaps some other genus. As regards other genera of the Peritrichia, Keiser (1921) described *Opercularia corethræ* from a European species of *Corethra*, Beattie and Howland (1929) found a species of *Sryphidia* on the tree-hole larvae of *Aedes geniculatus* Olivier in England, and in Germany Nenninger (1948) described *Pyxidium ventriosa* from *Corethra* sp., *Carchesium erlangensis* from *Aedes cinctus* Meigen, *Rhabdostyla dixiae* from *Dixa* sp. and *R. ovum* var. *culicidaeum* from culicine larvae. Graham (1939) mentioned ("*Porodon*") = *Prorodon* sp. as being present on thin and wasted larvae of *Culex peregrinus* Bergroth in New Zealand. *Prorodon* is a free-living genus of the Holotrichia, and this record was puzzling until Stout (1951) described his *Prorodon microstoma* as feeding solely on trophic *Vorticella microstoma*; it is likely that Graham's larvae were primarily infested with the latter protozoan. *Stentor* sp. was seen on larval *Aedes* spp. in America by Matheson and Hinman (1930).

There has been controversy as to the effect of these ectocommensals on their mosquito hosts. Giles (1902) suspected that they "may be the cause of the inexplicable disappearance of larvae . . . from situations where they were just before present in abundance," and suggested that they "may appropriate to themselves an undue share of the food that would otherwise fall to the share of their hosts." Jenkins and Knight (1952) also considered competition for plankton food at the larval mouthparts of definite significance. Howard et al. (1912) felt that such associations as these are, generally speaking, harmless, although they cited the case of an *Anopheles* larva being so overloaded with *Vorticella* that it died through an inability to turn its head to feed properly. Waterston (1918) observed that while Macedonian *Anopheles* complete their development despite the presence of heavy growths of *Vorticella*, in some cases long, branched hairs and the stellate hairs tend to break off as a result of the infestation so that the larvae drown through their inability to grip the water surface sufficiently. It was submitted by Frohne (1953) that larvae rendered sluggish by heavy infestations of ciliates must be especially vulnerable to the attacks of predators.

While some authors, such as Jenkins and Knight (1952), have reported that all infested larvae are able to pupate, even if they sometimes do so later than clean larvae, and that emergence of healthy adults subsequently takes place (Dyé, 1905), there is no doubt that on occasion one or more of the consequences of

infestation referred to above may bring about the death of the host. Thus Hamlyn-Harris (1930) noted in Queensland that larvae of *Anopheles annulipes* heavily overloaded with *Vorticella* sp. frequently die without pupating. Haddow (1946, 1948) found that in Uganda mosquito larvae of various genera and species often die at pupation, or else death occurs just after pupation, in the case of infestation with "stalked ciliates of the *Vorticella* and *Carchesium* types," and Micks (1950) gave an account of the complete destruction of a laboratory colony of *An. quadrimaculatus* by *V. microstoma*.

With the exception of the infestations studied by Micks (1950), which thrived in distilled water, most of the habitats from which ciliate-eating larvae have been collected seem to have been ground pools exposed to pollution. The instances cited by Haddow afford exceptions of particular interest in the light of the present findings. This author (1916) found infested larvae of *Erenopodites penicillatus* Edwards in the dark brown, polluted water in the shells of forest land snails, and (1948) reported similar infestations from various larvae in leaf axils including those of species of *Colocasia*, *Xanthosoma* and *Pandanus*. It being hardly to be expected that the water in such axils would be of intrinsically different constitution from that in the axils of the same and closely related plants in the Pacific, and as Haddow pointed out that most plant-axil larvae in Uganda bear at least a few stalked ciliates, the record seemed puzzling in view of my uniformly negative findings for this type of habitat. However, at the end of his paper Haddow (1948) noted that small tree frogs of several genera are common in Uganda leaf axils. Relatively small collections of water would obviously soon be polluted by such frogs, which are altogether lacking in the South Pacific.

**ROTIFERA.** The attachment of rotifers to mosquito larvae was observed on three occasions. In two instances the larvae concerned were of *Anopheles farauti* and were heavily infested with *Vorticella microstoma* (coll. nos. 6, Ancityum, and 30, Espiritu Santo). The rotifers from Ancityum were badly preserved and could not be identified beyond the genus, *Monostyla*. Those from Espiritu Santo proved to be referable to *Brachionus dimidiatus*, *B. quadridentatus* and the bdelloid genus *Habrotrocha*. All these rotifers were observed in life, creeping about over the anopheline larvae or attached to intersegmental grooves by means of the foot while browsing among the ectocommensal vorticellids. In some cases the attachment was sufficiently strong for the rotifers to remain affixed to the larvae following fixation in cold 10 per cent. formalin or 70 per cent. alcohol.

Large numbers of the bdelloid *Habrotrocha tridens* were similarly attached to the cuticle of all the larvae of *Tripteroides purpurata* collected from a tree hole at Nandarivatu, Viti Levu (coll. no. 325). These larvae bore no ectocommensals, but their stellate body hairs had trapped a considerable amount of frass amongst which the bdelloids were browsing. The same rotifer was also present in the frass at the bottom of the tree hole.

None of these rotifers were observed to harm the mosquitoes to which they were attached. Hinman (1931) quoted an instance of the destruction of mosquito larvae by rotifers. The temporary attachment of *Brachionus* spp. to *Daphnia* is of frequent occurrence according to Hartog (1901), but there does not appear to be any previous record of such a relationship between rotifers and mosquito larvae.

#### ENDOPHYTA

**FUNGI.** The genus *Coccomyces* was established by Keilin (1921), with *C. sicomyiae* Keilin from Kajang, Malaya, as the genotype. Keilin (1921, 1927) identified the host as a larva of (*Stegomyia scutellaris* Walker) = *Aedes* (*Stegomyia*) *scutellaris* (Walker), but more recent authors (e.g., Steinhause, 1917) have recognized that he was almost certainly dealing with *Aedes* (*Stegomyia*) *albopictus* (Skuse). The body cavity of the parasitized larva was a mass of sporangia which

"in the gills and the posterior segments were packed in solid masses completely filling these parts" (Keilin, 1921).

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5. *C. africanus* Walker, 1938. Sierra Leone. (*Anopheles costalis*)  
= *An. gambiae* (?) Kenya, *An. funestus* and *An. gambiae*. Hadlow, 1942.
6. *C. dodgei* Couch, 1915; Couch and Dodge, 1917 emend.—U.S.A., *An. crucians*.
7. *C. psorophorae* Couch, 1915.—U.S.A., *Psorophora ciliata*; Couch and Dodge, 1917.—*Aedes vexans*, *Psorophora howardi* and *Culiseta* (= *Theobaldia*) *inornata*.
8. *C. quadrangulatus* Couch, 1915.—U.S.A., *Anopheles* sp.; Couch and Dodge, 1917.—*An. punctipennis*, *An. crucians*, *An. quadrimaculatus* and *An. georgianus*.  
*C. quadrangulatus* var. *irregularis* Couch and Dodge, 1947. —U.S.A., *An. punctipennis*.  
*C. quadrangulatus* var. *lamborni* Couch and Dodge, 1917.—Malaya, (*Stegomyia scutellaris*) = *Aedes albopictus*. The authors found this species associated with *C. stegomyiae* on Keilin's type slide.
9. *C. penangulatus* Couch, 1945. —U.S.A., *Culex erraticus*.
10. *C. uranotaeniae* Couch, 1945. —U.S.A., *Uranotaenia sapphirina*.
11. *C. lativittatus* Couch and Dodge, 1947.—U.S.A., *An. crucians*.
12. *C. punctatus* Couch and Dodge, 1947. —U.S.A., *An. quadrimaculatus* and *An. crucians*.
13. *C. bitymetricus* Couch and Dodge, 1947. —U.S.A., *An. crucians*.
14. *C. sculptipennis* Couch and Dodge, 1917. —U.S.A., *An. punctipennis* and *An. crucians*.
15. *C. cribrosus* Couch and Dodge, 1917. —U.S.A., *An. punctipennis* and *An. crucians*.
16. *C. keilini* Couch and Dodge, 1947. —U.S.A., *An. crucians*.
17. *C. walkeri* Van Thiel, 1954. —Java, *An. tessellatus* (and Walker's (1938) type 1 *Coelomomyces* from *An. gambiae* and *An. funestus*, Sierra Leone).  
*C. eschariformis* Van Thiel, 1954. —Van Thiel proposed this name for Manalang's (1930) "Coccidium" from various Philippine *Anopheles* and for Walker's (1938) type 1 *Coelomomyces* from *An. gambiae* in Sierra Leone.

Most of the investigators concerned have noted the breadth of the hyphae and the nature of the mycelium. Specific diagnosis rests on these features, on the size and shape of the resting sporangium, and on the ornamentation and structure of the sporangial wall. Five of the species—*C. stegomyiae*, *C. notonectae*, *C. psorophorae*, *C. keilini* and *C. walkeri* (also type C of Muspratt, 1916) have a smoothly ovoidal resting sporangium the outer wall of which is pitted to a greater or lesser extent except in the case of *C. notonectae* and *C. walkeri*. In the other 13 species the sporangial wall, whether it is pitted or not, is distinctively sculptured.

Four species of *Coelomomyces* were encountered in the course of these studies. Three of the four larvae concerned were not noticed in the field, but were singled out for attention during the subsequent laboratory examination of alcohol-preserved material. In all cases the mycelium was too badly plasmolyzed for measurements to be of any value. The data presented herein were obtained from the phase contrast examination of the well-preserved resting sporangia as seen in whole—and teased-out "Sira" mounts of the parasitized larvae.

#### *Coelomomyces stegomyiae* Keilin, 1921 (Pl. 4, Figs. 17 and 19.)

One third instar larva of *Aedes* (*Stegomyiae*) *scutellaris* (Walker), collected from a half coconut shell at Lavanggu, Rennell (coll. no. 241), was infected. Thirty-eight other larvae of this mosquito (all instars) and 27 of *A. (Finlaya) albilibris* Edwards were also present but not parasitized. The husk was an old one, containing clean rainwater of pH 7.0. Brownish-yellow resting sporangia are

run longitudinally along both faces of the sporangium, and are only to be compared with those of Iyengar's two Indian species. *C. anophlelesica* has a distinctly flattened sporangium, more or less rounded in face view, with the ridges, or ribs, running in concentric or eccentric circles (Iyengar, 1935). *C. indiana*, however, is more or less circular in end view, as is the Queensland species, which from this aspect appears exactly like the example illustrated in Iyengar's Fig. 4g. In face view the thick, branching sporangial ribs of *C. indiana* are comparable with those of the *Coelomomyces* from *Ay. catasticta*. The size of the oval mature sporangium of the Indian parasite ranges from  $38\mu$  by  $25\mu$  to  $60\mu$  by  $36\mu$ . Although the sporangia of the species under consideration tend to be somewhat smaller and more elongate than those comprising the type material of *C. indiana*, the resemblances are such that the description of a new species would be unwarranted. The host mosquitoes breed in surface water, and the specific identity of a parasite having such a distinctive morphology cannot rest on the grounds of mere host and locality occurrence (see list, pp. 118-119.). The *Coelomomyces* of *Ay. catasticta* discussed herein is thus identified as *C. indiana* Iyengar.

From the data and photomicrograph (his Pl. 1, Fig. 1) given by Manalang (1930) it is obvious that his "Coccidium" from *Anopheles* spp. in the Philippines is very close to, if not conspecific with, *C. indiana*. The size of the mature resting sporangium (Manalang's "brownish yellow oocysts"; of this *Coelomomyces* ranges from  $31\mu$  by  $23\mu$  to  $66\mu$  by  $37\mu$  (average for 10 measured at random,  $44.8\mu$  by  $29.0\mu$ ), while the photomicrograph plainly illustrates thick longitudinal ridges which, Manalang informs us, appear as rounded knobs arising from the circular shell in section. Lan-Chou Feng (1933) reported "protozoan cysts" similar to Manalang's and having from eight to 11 longitudinal ridges in *Anopheles hyrcanus* var. *sinensis* and *Culex tritaeniorhynchus* in Woosung, China. Finally, Muspratt (1946) described a *Coelomomyces* having thick-walled, ribbed resting sporangia from five species of *Anopheles* and "one or two" larvae of *Culex simpsoni* in Rhodesia, stating that the sporangia vary considerably in size, but are mostly from  $40\mu$  to  $60\mu$  in length. Muspratt designated this species as his Type a, observing that the sporangium "appears very closely to resemble that of *Coelomomyces indiana* Iyengar."

The *Coelomomyces* which Manalang encountered in the Philippines is most certainly distinct from that which Walker (1938) referred to as his Type 4. The sporangia of the latter species have a crinkled or crenate wall, as is obvious from Walker's Pl. IV, Fig. 4, and are quite without longitudinal ribbing. Van Thiel (1954) thus erred in lumping Manalang's parasite together with Walker's Type 4 as a new species, *Coelomomyces ascariformis*. It should be noted that in any *Coelomomyces* infection a certain number of immature, thin-walled, smoothly ovoidal sporangia are often present. This applies even in the case of species in which the mature resting sporangium is heavily ribbed or otherwise sculptured (Iyengar, 1935, (c.); both Manalang (1930) and Lan-Chou Feng found such immature sporangia associated with thick-walled, ribbed, mature ones. A few obviously immature sporangia are present in the Kennell and Queensland material thus far discussed, and the thin, almost colourless walls of some of these are irregularly crinkled due to the action of the alcohol preservative which mature, thick-walled resting sporangia are better suited to withstand.

#### *Coelomomyces solomonis* n.sp. (Pl. 4, Figs. 20 and 21).

A dead and partly disintegrated fourth instar larva of *Anopheles punctulatus* collected from a pond in the bed of the Poha River, Guadalcanal (coll. no. 283), proved to be heavily infested with a *Coelomomyces* the sporangia of which completely filled the body cavity with the exception of the head capsule, where only a few were present. Thirty-two living *An. punctulatus* larvae of all instars were preserved from this station, but none of them were parasitized.

The mature resting sporangia are oval in face view, one surface being convex and the other more or less flat. The wall is of a yellowish colour, the relatively

5. *C. africanus* Walker, 1938. Sierra Leone. (*Anopheles costalis*)  
= *An. gambiae*. (?) Kenya, *An. funestus* and *An. gambiae*. Mad-  
dow, 1912.
6. *C. dodgei* Couch, 1945; Couch and Dodge, 1917 emend.—U.S.A., *An.  
cruciatus*.
7. *C. psorophorae* Couch, 1915.—U.S.A., *Psorophora ciliata*; Couch and  
Dodge, 1917. *Aedes vexans*, *Psorophora howardi* and *Culiseta* (=  
*Theobaldia*) *inornata*.
8. *C. quadrangulatus* Couch, 1945.—U.S.A., *Anopheles* sp.; Couch and  
Dodge, 1917.—*An. punctipennis*, *An. cruciatus*, *An. quadrimaculatus*  
and *An. georgianus*.  
*C. quadrangulatus* var. *irregularis* Couch and Dodge, 1917.—U.S.A.,  
*An. punctipennis*.  
*C. quadrangulatus* var. *lamborni* Couch and Dodge, 1917. Malaya,  
(*Stegomyia scutellaris*) = *Aedes albopictus*. The authors found  
this species associated with *G. stegomyiae* on Keilin's type slide.
9. *C. pentangularis* Couch, 1915. U.S.A., *Culex erraticus*.
10. *C. uranotactinae* Couch, 1915. U.S.A., *Uranotaenia sapphirina*.
11. *C. latititulus* Couch and Dodge, 1917.—U.S.A., *An. cruciatus*.
12. *C. punctatus* Couch and Dodge, 1917.—U.S.A., *An. quadrimaculatus* and  
*An. cruciatus*.
13. *C. bisymmetricus* Couch and Dodge, 1917.—U.S.A., *An. cruciatus*.
14. *C. sculptosporus* Couch and Dodge, 1917. U.S.A., *An. punctipennis* and  
*An. cruciatus*.
15. *C. cibrosus* Couch and Dodge, 1917. —U.S.A., *An. punctipennis* and *An.  
cruciatus*.
16. *C. keilini* Couch and Dodge, 1917.—U.S.A., *An. cruciatus*.
17. *C. walkeri* Van Thiel, 1951.—Java, *An. tessellatus* (and Walker's (1938)  
type 1 *Coelomomyces* from *An. gambiae* and *An. funestus*, Sierra  
Leone).
18. *C. ascariformis* Van Thiel, 1951. Van Thiel proposed this name for  
Manalang's (1930) "Coccidium" from various Philippine *Anopheles*  
and for Walker's (1938) type 4 *Coelomomyces* from *An. gambiae*  
in Sierra Leone.

Most of the investigators concerned have noted the breadth of the hyphae and the nature of the mycelium. Specific diagnosis rests on these features, on the size and shape of the resting sporangium, and on the ornamentation and structure of the sporangial wall. Five of the species—*C. stegomyiae*, *C. noronectae*, *C. psoro-  
phorae*, *C. keilini* and *C. walkeri* (also type C of Muspratt, 1946)—have a smoothly  
ovoidal resting sporangium the outer wall of which is pitted to a greater or lesser  
extent except in the case of *C. noronectae* and *C. walkeri*. In the other 13 species  
the sporangial wall, whether it is pitted or not, is distinctively sculptured.

Four species of *Coelomomyces* were encountered in the course of these studies.  
Three of the four larvae concerned were not noticed in the field, but were singled  
out for attention during the subsequent laboratory examination of alcohol-pre-  
served material. In all cases the mycelium was too badly plasmolysed for  
measurements to be of any value. The data presented herein were obtained from  
the phase contrast examination of the well-preserved resting sporangia as seen  
in whole—and teased-out "Sir" mounts of the parasitized larvae.

#### *Coelomomyces stegomyiae* Keilin, 1921 (Pl. 4, Figs. 17 and 19.)

One third instar larva of *Aedes* (*Stegomyia*) *scutellaris* *scutellaris* (Walker),  
collected from a half coconut shell at Lavanggu, Rennell (coll. no. 241), was in-  
fected. Thirty-eight other larvae of this mosquito (all instars) and 27 of *A. (Finlaya)  
abilis* Edwards were also present but not parasitized. The husk was an old  
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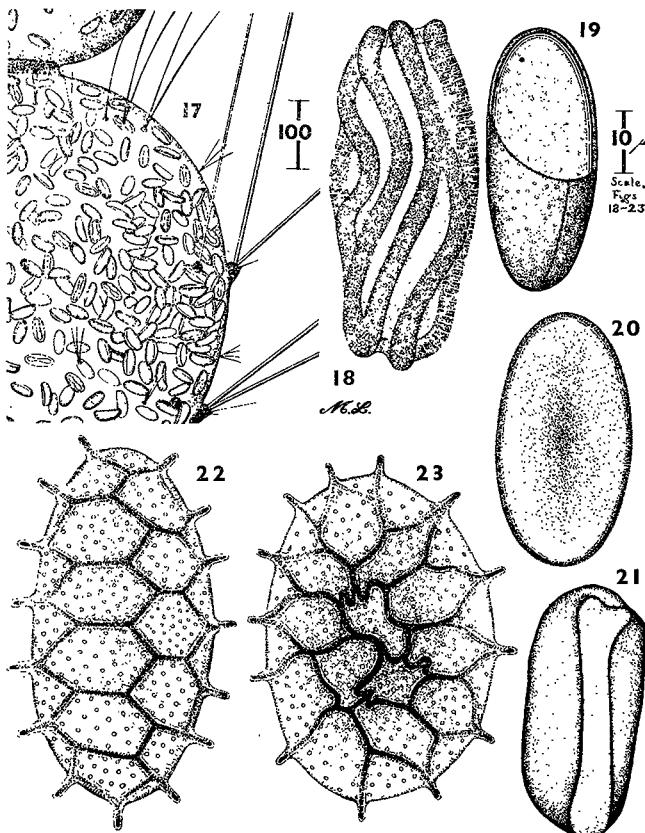


FIG. 17.—Habit study, sporangia of *Coelomomyces stegomyiae* Keilin in thorax of *Aëdes s. scutellaris* (coll. no. 241). Unstained "Sira" mount. 152 X. FIG. 18.—Sporangium, *Coelomomyces indiana* Iyengar, from *Aëdomya catasticta* (coll. no. 361). Unstained "Sira" mount. 1,380 X. FIG. 19.—Sporangium, *C. stegomyiae* from *A. s. scutellaris* (coll. no. 211). Unstained "Sira" mount. 1,380 X. Semi-diagrammatic. FIGS. 20 and 21.—*Coelomomyces solomonii* n.sp. from *Anopheles punctulatus* (coll. no. 283). FIG. 20.—Surface view of unsporulated sporangium. FIG. 21.—Empty sporangial shell. Both figures from an unstained "Sira" mount. 1,380 X. FIGS. 22 and 23.—*Coelomomyces carriensis*, n.sp. from *An. jacutai* (coll. no. 349). Illustrating the sculpturing of both faces of the sporangium. Both figures from an unstained "Sira" mount. 1,380 X.

present throughout the body cavity of the larva in question, being most numerous in the abdomen and thorax (Fig. 17). Individual sporangia are ovoidal in front view (Fig. 19). In side view one surface is seen to be convex, while the other is flattened or somewhat concave so as to lend the sporangium a boat-shaped appearance (Keilin, 1921; Fig. 7G). The outer wall is thick, strongly pigmented and minutely pitted, while the inner one is hyaline and relatively thin (Fig. 19). The cytoplasmic contents are multinucleated and fill most of the available space, but fine structure, other than the physical fact of the presence of nuclei, cannot be made out in material preserved in this fashion. A preformed dehiscence slit is sometimes evident along the convex surface of the sporangium. Fifty consecutive sporangia were measured, their length ranging from  $28.3\mu$  to  $55.7\mu$  (av.  $39.1\mu$ ) and their breadth ranging from  $11.9\mu$  to  $21.1\mu$  (av.  $17.9\mu$ ). The wall is not more than  $2.5\mu$  thick.

From these data the *Coccomyzae* under consideration bears comparison with *C. stegomyiae*, *C. psorophorae* and *C. keilini*. *C. psorophorae* can be eliminated at once on grounds of size, for this species has the largest resting sporangia ( $46\mu$  to  $100\mu$  by  $37\mu$  to  $67\mu$ ), so far described for the genus (Couch, 1915) with a wall of up to  $10\mu$  in thickness. *C. keilini* also has a very thick wall ( $3\mu$  to  $7\mu$ ), the pits in which appear star-shaped as one focuses downwards (Couch and Dodge, 1917). The size of the resting sporangium is again beyond that of the one under discussion ( $58\mu$  to  $71\mu$  by  $31\mu$  to  $46\mu$ ).

The Solomon Island parasite is indeed somewhat smaller than *C. stegomyiae* as defined by Keilin, who gave the measurements of the resting sporangium as  $37.5\mu$  to  $57\mu$  by  $20\mu$  to  $30\mu$ . (Couch and Dodge reported that some sporangia on Keilin's type slide run up to  $63\mu$  by  $37\mu$ .) However, the size range of the Rennell material in considerable part overlaps that of the type, and moreover, a greater amount of shrinkage is to be expected in specimens preserved in alcohol as compared with Keilin's formalin sample. As in other respects the resting sporangia compare very closely indeed, and the hosts are systematically close to one another and utilize similar larval habitats, the present *Coccomyzae* is identified as *C. stegomyiae* Keilin. It is something of a coincidence that this species, which has not been reported since the first discovery, should now be recorded from a new host which happens to be the very one with which Keilin thought he was dealing. Haddow (1948) recorded, but failed to describe a *Coccomyzae* from larval *Aedes (Stegomyia) simpsoni* Theobald, a leaf axil breeder in Uganda.

#### *Coccomyzae indiana* Iyengar, 1935 (Pl. 4, Fig. 18).

This species is recorded from a single third instar larva of *Aedomyia catasticta* from a semi-permanent roadside seepage pond near Liverpool Creek, 24 kilometres south of Innisfail, Queensland (coll. no. 361). None of the 17 other larvae of the same species preserved from this collecting station were parasitized. Neither were four fourth instar larvae of *Anopheles b. bancroftii* which were also taken from this pond.

The brownish-yellow sporangia pack all parts of the body cavity with the exception of that of the head and siphon, in which relatively few are present. They are ovoid to elongate-ovoid in shape, and the wall is longitudinally ridged. The ridges range from  $2.5\mu$  to  $3.5\mu$  in height, and frequently anastomose: they are minutely pitted, the pits appearing as light striae in side view (Fig. 18). Fifty consecutive resting sporangia gave the following measurements: length,  $35.5\mu$  to  $54.3\mu$ ; breadth,  $21.7\mu$  to  $31.0\mu$ . Typical examples are a little more than twice as long as broad, with an average of  $48.4\mu$  by  $23.0\mu$ , but oval sporangia measuring some  $33\mu$  by  $25\mu$  are quite common.

While two of the American species—*C. dodgri* and *C. lativittatus*—have longitudinally banded sporangia, the bands of the former are not very distinct and those of the latter are longitudinal on one side and irregular or transverse on the other. The striated and conspicuously raised ridges of the present species

run longitudinally along both faces of the sporangium, and are only to be compared with those of Iyengar's two Indian species. *C. anophelesica* has a distinctly flattened sporangium, more or less rounded in face view, with the ridges, or ribs, running in concentric or eccentric circles (Iyengar, 1935). *C. indiana*, however, is more or less circular in end view, as is the Queensland species, which from this aspect appears exactly like the example illustrated in Iyengar's Fig. 4g. In face view the thick, branching sporangial ribs of *C. indiana* are comparable with those of the *Coelomomyces* from *Ay. catalactica*. The size of the oval mature sporangium of the Indian parasite ranges from  $38\mu$  by  $25\mu$  to  $60\mu$  by  $36\mu$ . Although the sporangia of the species under consideration tend to be somewhat smaller and more elongate than those comprising the type material of *C. indiana*, the resemblances are such that the description of a new species would be unwarranted. The host mosquitoes breed in surface water, and the specific identity of a parasite having such a distinctive morphology cannot rest on the grounds of mere host and locality occurrence (see list, pp. 118-119). The *Coelomomyces* of *Ay. catalactica* discussed herein is thus identified as *C. indiana* Iyengar.

From the data and photomicrograph (his Pl. 1, Fig. 1; given by Manalang (1930) it is obvious that his "*Coccidium*" from *Anopheles* spp. in the Philippines is very close to, if not conspecific with, *C. indiana*. The size of the mature resting sporangium (Manalang's "brownish yellow oöcysts") of this *Coelomomyces* ranges from  $31\mu$  by  $25\mu$  to  $66\mu$  by  $37\mu$  (average for 10 measured at random,  $41.8\mu$  by  $29.0\mu$ ), while the photomicrograph plainly illustrates thick longitudinal ridges which Manalang informs us, appear as rounded knobs arising from the circular shell in section. Lan-Chou Feng (1933) reported "protozoan cysts" similar to Manalang's and having from eight to 11 longitudinal ridges in *Anopheles hyrcanus* var. *sinensis* and *Culex tritaeniorhynchus* in Woosung, China. Finally, Muspratt (1916) described a *Coelomomyces* having thick-walled, ribbed resting sporangia from five species of *Anopheles* and "one or two" larvae of *Culex simpsoni* in Rhodesia, stating that the sporangia vary considerably in size, but are mostly from  $40\mu$  to  $60\mu$  in length. Muspratt designated this species as his Type a, observing that the sporangium "appears very closely to resemble that of *Coelomomyces indiana* Iyengar."

The *Coelomomyces* which Manalang encountered in the Philippines is most certainly distinct from that which Walker (1938) referred to as his Type 4. The sporangia of the latter species have a crinkled or crenate wall, as is obvious from Walker's Pl. IV, Fig. 4, and are quite without longitudinal ribbing. Van Thiel (1954) thus erred in lumping Manalang's parasite together with Walker's Type 4 as a new species, *Coelomomyces ascariformis*. It should be noted that in any *Coelomomyces* infection a certain number of immature, thin-walled, smoothly ovoidal sporangia are often present. This applies even in the case of species in which the mature resting sporangium is heavily ribbed or otherwise sculptured (Iyengar, 1935, etc.); both Manalang (1930) and Lan-Chou Feng found such immature sporangia associated with thick-walled, ribbed, mature ones. A few obviously immature sporangia are present in the Kennell and Queensland material thus far discussed, and the thin, almost colourless walls of some of these are irregularly crinkled due to the action of the alcohol preservative which mature, thick-walled resting sporangia are better fitted to withstand.

#### *Coelomomyces solomonis* n.sp. (Pl. 4, Figs. 20 and 21).

A dead and partly disintegrated fourth instar larva of *Anopheles punctulatus* collected from a pond in the bed of the Poha River, Guadalcanal (coll. no. 283), proved to be heavily infested with a *Coelomomyces* the sporangia of which completely filled the body cavity with the exception of the head capsule, where only a few were present. Thirty-two living *An. punctulatus* larvae of all instars were preserved from this station, but none of them were parasitized.

The mature resting sporangia are oval in face view, one surface being convex and the other more or less flat. The wall is of a yellowish colour, the relatively

thick outer layer and the thin, hyaline inner one (together about  $1\mu$  thick) showing up clearly in a whole mount. Mature sporangia are quite smooth and do not exhibit pitting, this feature distinguishing them from those of *C. stegomyiae* which they otherwise closely resemble. Some empty sporangial shells are present. These are boat-shaped in side view, and in surface view appear as illustrated in Fig. 21. Fifty consecutive resting sporangia were measured, with the following results.—length,  $32\cdot1\mu$  to  $43\cdot7\mu$  (av.,  $38\cdot9\mu$ ); breadth,  $18\cdot5\mu$  to  $23\cdot9\mu$  (av.,  $22\cdot0\mu$ ); thickness,  $10\cdot0\mu$  to  $21\cdot1\mu$  (av.,  $11\cdot3\mu$ ).

Only two of the described species of *Coelomomyces*, *C. notonectae* and *C. walkeri*, have resting sporangia with a smooth and unpitted wall. The measurements of the sporangium of the former species have not been recorded, but Keilin (1927) observed that from a careful study of Bogoyavlensky's figures it is apparent that the dimensions of the various stages are not very far from those of *C. stegomyiae*. I have not been able to procure a copy of the paper in question (Bogoyavlensky, N. 1922, *Zografus notonectae* n.g., n.sp. *Arch. Russ. Protistol. Soc.*, 1, 113-119). Keilin (1927) also mentioned that Bogoyavlensky's figures show the sporangial wall of *C. notonectae* as single, uniform and structureless, but suggested that he might easily have overlooked the fine structure of this envelope.

The resting sporangia of *C. walkeri* from the Javanese *Anopheles tessellatus* range from  $55\mu$  to  $63\mu$  in length and from  $33\mu$  to  $42\mu$  in breadth (Van Thiel, 1954), while the Type 1 of Walker (1938)—if this is indeed conspecific with the Indonesian parasite and not merely an immature stage of Walker's Type 1 *Coelomomyces*, *C. ascariformis* Van Thiel—ranges from  $45\mu$  to  $60\mu$  in length. Both sets of figures are beyond the maximum dimensions recorded for the species under consideration. *C. notonectae*, if its sporangia are of similar size to those of *C. stegomyiae* as indicated by Keilin (1927), is more comparable with the Guadalcanal parasite. Until *C. notonectae* has been redescribed, however, detailed comparisons between it and the other members of the genus cannot be made. It is thus felt best to describe the *Coelomomyces* of *Anopheles punctulatus* as a new species. This parasite is accordingly designated *Coelomomyces solomonis* n.sp., having the characters outlined herein. The type slide has been deposited in the collection of the Dominion Museum, Wellington.

#### *Coelomomyces cairnsensis* n.sp. (Pl. 4, Figs. 22 and 23).

This species is described from a late second or early third instar larva of *Anopheles farauti* dipped from a ponded stream 24 kilometres north of Cairns, Queensland (coll. no. 349). None of the other larvae (including those of three species of *Culex* and one of *Uranotaenia*) preserved from this collecting station were parasitized.

The large, horn-coloured resting sporangia pack the thoracic cavity of the infected larva and are scattered through the abdomen. They are ovoid to elongate-ovoid in surface view and sausage-shaped in side view. The outer sporangial wall is raised up into ridges ranging from  $1\cdot0\mu$  to  $1\cdot5\mu$  in width and from  $3\cdot0\mu$  to  $5\cdot0\mu$  in height. These ridges form a network of hexagons on the convex face of the sporangium (Fig. 22), from seven to 10 complete hexagons and portions of others usually being apparent in surface view. On the concave face the outermost ridges enclose roughly hexagonal to irregular areas, while the innermost ones are often strongly convoluted (Fig. 23). The areas of the sporangial wall enclosed by the ridges exhibit conspicuous pitting. These pits, which show to advantage in whole mounts examined by phase contrast, are usually rounded, about  $0\cdot7\mu$  in diameter and spaced from  $1\cdot2\mu$  to  $2\cdot5\mu$  apart. The measurement of 25 consecutive resting sporangia seen in surface view and 15 seen in side view gave the following results.—length,  $41\cdot8\mu$  to  $61\cdot2\mu$  (av.,  $53\cdot3\mu$ ); breadth,  $26\cdot5\mu$  to  $35\cdot5\mu$  (av.,  $31\cdot7\mu$ ); thickness,  $14\cdot4\mu$  to  $26\cdot2\mu$  (av.,  $19\cdot6\mu$ ).

Only two of the *Coelomomyces* to which specific names have been assigned bear any resemblance to the one under discussion. These are *C. africanus* and

*C. ascariformis* (this name being understood herein as referring only to the type 4 sporangium of Walker, 1938). Both of these species from Sierra Leone exhibit crenation of the sporangial wall. *C. africanus* is the smaller of the two, the sporangia measuring 25 $\mu$  to 35 $\mu$  in length (Walker, 1938). This species can be eliminated from further consideration as its sporangium does not attain the minimum length of that of the Queensland parasite. *C. ascariformis*, though, has sporangia which range from 45 $\mu$  to 60 $\mu$  in length (Walker, 1938) and which are thus closely comparable in size with those of the latter species. Unfortunately, Walker failed to note whether or not the sporangial wall of *C. ascariformis* exhibits pitting. In fact, beyond mentioning the length range of the sporangium, he failed to publish any morphological data concerning this fungus. It would appear from Walker's Plate IV, Fig. 1, that the sporangial wall of *C. ascariformis* is ridged on rather similar lines to that of the present species, but that the ridges are much thicker and lower than in the case of the latter. Muspratt (1916) reported thick-walled resting sporangia (his type *c Coelomomyces*) from larvae of *Anopheles gambiae* and *An. squamosus* in Rhodesia. These range in length from about 50 $\mu$  to 70 $\mu$ . Muspratt, who drew attention to the resemblance between these and Walker's type 4, illustrated (his Pl. 1, Fig. 2) broadly oval sporangia having a network of low, thick ridges enclosing "large pits". It is considered that in all probability Muspratt's type *c Coelomomyces* is referable to *C. ascariformis*. Perhaps the "objection resembling ova of *Ascaris*" which Gibbons (1932) noted in the ovaries of (*An. costalis*) = *An. gambiae* in Uganda are also referable to *C. ascariformis* or to *C. africanus*.

It is most desirable that full morphological accounts of *Coelomomyces africanus* and *C. ascariformis* should be published. In the meantime it is not possible to assign material from other hosts and localities to these species. In any case, although the sporangia of the present species resemble those of *C. ascariformis* in size, they differ radically in possessing high, narrow ridges enclosing minutely pitted areas which are hexagonal on the convex face and roughly hexagonal to irregular and convoluted on the concave face. The fungus under discussion should thus be regarded as a distinct species, and it is accordingly designated *Coelomomyces cairnsensis* n.sp. having the characters designated herein. The type slide is in the collection of the Dominion Museum, Wellington, while a paratype has been deposited in that of the Department of Entomology, University of Queensland.

#### ENDOZOA

##### PROTOZOA

###### MASTIGOPHORA. *Crithidia fasciculata* Léger, 1902 (Pl. 5, Figs. 24 and 25).

Protomonadid flagellates were discovered in the mid- and hind gut of a number of fourth instar larvae of *Anopheles farauti* at Pallikulo, Espiritu Santo (coll. no. 17) and Ibu Farm, Guadalcanal (coll. no. 268). Associated *Culex annulirostris* larvae, present in both instances, were uninfected.

No attached forms were seen in whole mounts of the alimentary tract, all the flagellates noted being actively motile. As seen in fresh saline preparations of the gut contents they made rapid progresional movements, sometimes rotating about the longitudinal axis, the body moving in a jerky side-to-side fashion. After being exposed to the heat and light of the microscope lamp for a short time they tended to attach themselves to the cover slip by the tip of the flagellum, subsequently rotating about the point of attachment. The short, stubby body was swollen anteriorly, and the relatively thick flagellum was usually about as long as the body itself.

In Giemsa-stained smears a large nucleus is seen to be located more or less centrally at the point where the body exhibits constriction. The cytoplasm is alveolar, a clear zone being evident towards the truncate anterior end. A thick flagellum runs back through this clear zone, originating just in front of a rod-shaped

kinetoplast positioned anteriorly to the nucleus. The flagellate (excluding its flagellum) ranges from  $8.4\mu$  to  $10.3\mu$  in length and averages just under  $3\mu$  in breadth at the widest part of the body (Figs. 24 and 25).

Many authors have described or recorded flagellates of the family Trypanosomatidae Doflein from mosquitoes. Most of the records up to 1941 are listed in the publications of Weynon (1926), Speer (1927) and Wallace (1943). The latter investigator redescribed *Criphidia fasciculata* Léger 1902 and gave a useful account of the synonymy of this species. He also recognized four species of *Herpetomonas* from mosquitoes. The genus *Criphidia* was shown by Wallace to lack an undulating membrane throughout the life cycle, *Herpetomonas* having stages with such a membrane. In *Leptomonas*, which also lacks an undulating membrane, the kinetoplast is anteriorly positioned, but in *Criphidia* this structure, although located in advance of the nucleus, is in the median or posterior part of the body. Members of the latter genus typically have a short, anteriorly truncate body with an anterior funnel-like depression through which passes the axoneme.

The flagellate under discussion is referable to the genus *Criphidia*. It compares closely with *C. fasciculata* as redescribed by Wallace (1913) in its general morphology, but is somewhat larger— $8.4\mu$  to  $10.3\mu$  in length by just under  $3.0\mu$  in maximum breadth, as compared with Wallace's figures of  $6\mu$  to  $8\mu$  by  $2\mu$  to  $3\mu$ . The figures published by Novy et al. (1907) agree with those of Wallace, but in his description of the type material Léger (1902) gave  $10\mu$  as the maximum length. Novy et al. noticed the readiness of motile flagellates of this species to become attached to the cover glass by means of the tip of the flagellum, and thereafter to sway and wriggle about the point of attachment.

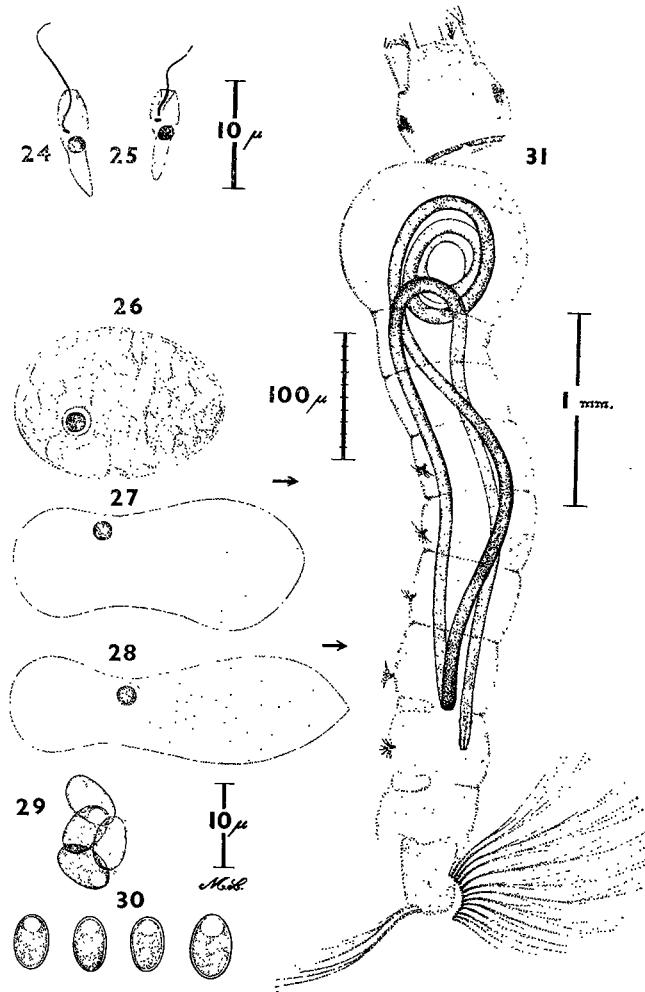
Most of the field records of *C. fasciculata* have been from adult mosquitoes rather than larvae, although Wallace (1943) succeeded in infecting *Aedes* and *Culex* larvae by leaving them for two minutes in a rich broth culture of the flagellate and pointed out that Patton's report that about 95 per cent. of the larvae and pupae of *Culex fatigans* from a Madras well were parasitized by "*Herpetomonas culicis*" actually refers to *C. fasciculata*.

It is considered that the flagellate of *Anopheles farauti* from Espiritu Santo and Guadalcanal is referable to *Criphidia fasciculata* Léger, 1902, the host- and locality records being new.

**Sporozoa.** Gregarinida. While one of three fourth instar larvae of *Anopheles punctulatus* dipped from a slowly flowing stream at Ilu Farm, Guadalcanal (coll. no. 257) was being examined for ciliates, it was noticed that three organisms exhibiting vigorous peristaltic movement were present in the thoracic cavity.

The integument was opened up with a scalpel and the organisms, emerging into a drop of saline solution on the slide, showed themselves to be gregarine trophozoites (Figs. 26-28). At first they moved about actively, measuring some  $270\mu$  by  $86\mu$  in their greatest dimensions when fully extended (Fig. 28). They soon rounded up and became motionless (Fig. 26), in this state measuring about  $165\mu$  by  $120\mu$ . The large vesicular nucleus, some rounded and indeterminate cytoplasmic inclusions and traces of the myonemes could be made out by phase contrast.

It is not possible to assign this parasite to its position within the order Gregarinida, for no other life history stages could be discovered. There would appear to be little likelihood of its belonging to the suborder Schizogregarinaria, though, for but one genus, *Cavillerella*, all the members of which are restricted to the lumen of the gut of dipterous larvae, parasitizes mosquitoes. Acephaline eugregarines of the genera *Lankesteria* and *Diplocystis* have been recorded from mosquito larvae, the former from the lumen of the gut (Weynon, 1926) and the latter from the haemocoel (Léger and Duboscq, 1903). Van Thiel (1954) has recently described *Diplocystis melschaari* from *Anopheles farauti* in Dutch New Guinea. It is unfortunate that his material was confined to two gameteoysts from the stomach wall of the infected mosquito, and that the present material is limited



Figs. 24 and 25.—*Crithidia fasciculata* Léger from *Anopheles farauti* (coll. no. 17) Giensia. 2,140 X. Figs. 26-28.—Gregarine from thoracic cavity of *An. punctulatus* (coll. no. 257). Fig. 26.—Rounded-up trophozoite. Figs. 27 and 28.—Outline sketches from photomicrographs to illustrate successive stages in progresional movement. From life. 255 X. Figs. 29 and 30.—*Thelohania opacita* Kudo from the haemocoels of *Culex annulirostris* (coll. no. 30). From life. 1,700 X. FIG. 29.—Tetrasporous pansporoblast. FIG. 30.—Spores, illustrating size range. FIG. 31.—*Agamomermis* in early third instar larva of *An. annulipes* (coll. no. 370). Unstained "Sira" mount. 39 X.

to trophozoites, thus precluding the drawing of any comparisons between two gregarines which in view of their host—and geographical occurrence might prove to be closely related to one another.

SPOZOZA. Microsporidia. *Thelohania opacita* Kudo, 1922 (Pl. 5, Figs. 29 and 30).

Pansporoblasts and mature spores of a microsporidian were discovered in the haemocoel of a fourth instar larva of *Culex annulirostris* taken from a transient pool at Lugaunille, Espíritu Santo (coll. no. 30).

The pansporoblasts were all tetrapsorous, and the mature spores were ovoid and circular in end view. A more or less rounded clear space was clearly visible by phase contrast, towards one pole. The fresh spores ranged from  $6.2\mu$  to  $8.0\mu$  (av.  $6.7\mu$ ) by  $3.8\mu$  to  $5.0\mu$  (av.  $4.3\mu$ ) in their greatest dimensions. No ill effects were noted in the host, but these could have been masked by a prolific growth of *Characium* which completely covered the posterior parts of the body. The parasite was only noted incidentally, the spores coming out into a saline drop in the course of a routine gut dissection.

There is little doubt but that this parasite is referable to *Thelohania opacita* Kudo, 1922, originally described from the larvae of *Culex* spp. in the U.S.A. Although octosporous pansporoblasts exceed tetrapsorous ones in number in this species (Kudo, 1924), the appearance of the pansporoblasts from *C. annulirostris* (cf. Kudo, 1924, Pl. XVII, Fig. 31) and the shape and morphology of the mature spores is exactly as in *T. opacita*. The only material difference is in the absolute size of the spores. Kudo noted the occurrence of large ( $8.0\mu$  to  $8.5\mu$  by  $1.5\mu$  to  $5.5\mu$ ) and small ( $5.5\mu$  to  $6.0\mu$  by  $3.5\mu$  to  $4.0\mu$ ) spores, the dimorphism being bound up with the octosporous and tetrapsorous spore formation. None of the spores measured at Espíritu Santo were less than  $6.2\mu$  in length, and dimorphism was not apparent, the microsporidians presenting a graded series intermediate in size between Kudo's two series. It is felt that these are hardly sufficient grounds for the description of a new species, and that on the available evidence the New Hebridean parasite should be regarded as conspecific with *Thelohania opacita*.

Microsporidians are as yet unknown from Pacific anophelines. *T. opacita* restricts its attentions to culicines, for the parasites of this order which attack mosquitoes are specific to the genus, although not to the species, of the host (Kudo, 1924a). Several species of *Thelohania* have been described from *Anopheles* elsewhere, and while some of these occur in temperate countries, at least four species, having at least seven anopheline hosts, are found in India (Sen, 1941). According to Sen (1941), *T. leggi* Hesse, a pathogenic species occurring in Europe and the U.S.A. (Kudo, 1921a), is perhaps the commonest microsporidian of the Indian larvae. As affected larvae seldom achieve pupation, Kudo (1921) suggested that the artificial dissemination of infected larval tissue might prove a useful biological control technique. It is high time that this suggestion were followed up. Although a more intensive search will have to be made in the western Pacific before the absence of microsporidians specific for *Anopheles* can be established, their non-discovery to date indicates that, even if they are present there, they must be rare and localized. Under these circumstances experimental introductions of known species pathogenic for these mosquitoes might well be contemplated.

#### NEMATODA.

*Agamomermis* sp. (Pl. 5, Fig. 31).

Nine out of 13 third and fourth instar larvae of *Anopheles annulipes* collected from a ponded stream 16 kilometres south of Townsville, Queensland (coll. no. 370) proved to be parasitized by mermithids. Twelve larvae of *Anopheles b. bancroftii*, three of *Culex basicinctus* and two of *Aëdomyia catasticta* preserved from this station were uninfected.

The mermithids lie in coils in the thorax and along the length of the abdomen of the parasitized larvae (Fig. 31). Large examples occupy the greater part of

the body cavity, and the worms range from about 8 mm to 15 mm in length. The thickness of the worm ranges from  $55\mu$  in the younger examples (Fig. 31) up to  $115\mu$ . As many as six lengths may snake back and forth along the abdomen. In all but one of the infections the coils stop short of the eighth abdominal segment. All of the nematodes are positioned ventro-laterally and ventrally in relation to the larval gut.

Stabler (1952) briefly summarized records of nematodes known from adult mosquitoes, and discussed a mermithid from larval *Aedes vexans*, *Culex salinarius* and *C. pipiens* which were collected in Pennsylvania, U.S.A., in 1911. West (1951) referred to a similar nematode which parasitizes mosquitoes in the Canadian arctic and subarctic. Gendre (1909) found mermithids in larval *Aedes aegypti* in French Guiana, while Muspratt (1915) discovered a similar parasite in larvae of this and seven other tree-hole breeding mosquitoes (six *Aedes* and one *Culex*) in Northern Rhodesia. The latter author also reported finding mermithids in larval anophelines (including *An. gambiae*) and culicines in Rhodesia and the Eastern Transvaal, and mentioned that the collection of the South African Institute for Medical Research includes similarly infested anopheline larvae from the Union of South Africa and the Belgian Congo. Iyengar (1929) discussed a mermithid which parasitizes anopheline larvae (including those of *An. minimus* var. *varuna*) in Bengal, Baylis (1936) publishing fuller information from Iyengar concerning this species. Walandouw (1934) described allied parasites from larvae of *Anopheles leucophrys* Dönnitz var. in Sumatra.

None of the mermithids from mosquito larvae have been determined specifically, and all of them are referable to *Aganomermis* Stiles, which Speer (1927) defined as "A collective group to contain immature Mermithidae not developed to a stage which permits a determination of the genus." More than one species would appear to be concerned, for Gendre (1909) stated that two worms were always present, one large and one small, in the infestations which he encountered, and Muspratt (1945) wrote that his mermithids exhibited sexual dimorphism and illustrated a larva (in Fig. 5) of *A. aegypti* containing two parasites. The other investigators concerned were all dealing with ground pool mosquitoes, and in these single infections are the rule except in the case of *An. leucophrys* (Walandouw, 1934). Iyengar (1929) mentioned that but one worm emerged from each larva, and Baylis quoted the former author as stating that only a single nematode is present in each infested larva in nature and that although as many as 20 mermithids may enter a single larva under laboratory conditions only one of these remains after four days, the fate of the others being unknown. Stabler (1952) examined 90 mermithid-infested larvae of his three mosquito hosts, and noted only one containing more than a single parasite. In each of the nine infestations discussed herein the larva concerned contained but one nematode.

Walandouw, Muspratt, and Iyengar (in Baylis, 1936) noted the presence of a terminal spine or papilla. Such a structure was not referred to by Stabler, and is lacking in the Queensland worms, one end of which is tapered and more or less truncate (Fig. 31) while the other is smoothly rounded. Muspratt gave the size-range for his species as  $650\mu$  to  $700\mu$  by  $20\mu$  (presumably post-infective larvae) to 25mm to 33mm by  $115\mu$  to  $165\mu$  in the case of emerging mermithids. Iyengar's species ranges from 5mm to 8mm in length and from  $63\mu$  to  $110\mu$  in thickness at the time of emergence from the larva (in Baylis, 1936); Walandouw's measures from 17mm to 20mm in length and from  $52\mu$  to  $88\mu$  in thickness, while that dealt with by Muspratt ranges from 9mm to 18mm (av., 11.7mm) in length at emergence. It is, of course, not possible to give comparable measurements for the present mermithid, as this is known only from preserved material. However, the smallest examples seen were as long as the largest of those studied by Iyengar and differ further from these, and from the mermithids described by Walandouw and Muspratt, in the absence of a posterior spine. While they are of comparable length

to Stabler's parasite, they differ from this biologically in that the latter species is restricted to the thoracic cavity of the host and never invades the abdomen.

While at least four different mermithid species would appear to be separable on biological and morphological grounds from a consideration of the available data, the establishment of species would have to be based on quite arbitrary criteria in the absence of adult material. The mermithid described herein is accordingly merely designated *Aganomermis* sp.

Wherever *Aganomermis* has been noted in mosquito larvae the incidence of infection has been high. Thus Gendre (1909) reported that although parasitized lots of larvae were rare, all the larvae in one of his two infested batches contained mermithids. Muspratt (1943) noted infection rates of from 70 to 80 per cent. for all his hosts with the exception of *Aedes (Aëdimorphus) marshalli* Theobald, and Stabler (1952) found 90 parasitized larvae out of 217 examined. A certain degree of host specificity appears to operate, for Muspratt noted one species as being refractory to infection, Stabler found only four examples of *Culex salinarius* infected out of 53 examined (as compared with 10 out of 18 *C. pipiens* and 76 out of 146 *Aedes texanus*), while in Queensland, although nine out of 13 *An. annulipes* larvae contained worms, 17 larvae of three other species from the same habitat did not.

All the investigators concerned are in agreement that the death of an infected larva invariably follows the emergence of a mermithid from its body, lyengar (1929) attributing this to the loss of the body fluid through the rupture caused by the worm. Whether or not the adult mosquitoes which emerge from uninfected developmental stages can carry infective larval mermithids to new habitats, is unknown. There are no records of such mermithids from larvae of *Aedes polynesiensis* or indeed of any of the other *Wuchereria* vectors of the *scutellaris* group, although Rosen (1954) has recently noted the occurrence of tiny nematode larvae, sharply pointed at the extremities and even smaller than third stage larvae of *Wuchereria bancrofti* or *Dirofilaria immitis*, in adult mosquitoes of the Society Islands. The insects concerned, *A. polynesiensis*, *A. egypti* and *Culex p. fatigans*, were reared from wild-caught larvae and pupae in which infections were not observed. An intensive study of the distribution, host specificity and pathogenicity of *Stegomyia* mermithids might well be made with a view to the possible use of such a species as the one parasitizing African tree hole larvae of this subgenus (Gendre, 1909; Muspratt, 1915) against the members of the *scutellaris* complex in the Pacific.

#### LARVAL HABITAT CLASSIFICATION

All members of the family Culicidae have aquatic developmental stages, the larval habitats of the great majority comprising one or more kinds of bodies of standing fresh water. Only a small minority of species utilize standing brackish water or certain situations in flowing streams.

Many of the ecological niches involved are highly specialized. Most of them are characterized by small size and by comparison with major freshwater bodies—relative impermanence. Lakes and streams are of minor importance as mosquito larval habitats. It is these latter waters, however, that have provided the greater part of the raw materials of limnology. This is well illustrated by the fact that, in their recent ecological consideration of inland water communities, Hesse et al. (1951: chapters 17 to 19) devoted 33 pages to lakes, 19 to running waters, 19 to various specialized communities but less than seven to ponds and temporary pools.

Limnologists would seem to have devoted a disproportionate amount of attention to those ponds and marshes which represent stages in the senescence of lakes. Many of them have altogether disregarded the second and third types of pond defined by Welch (1935), those natural ones which have not been preceded

by a lake and those which owe their origin to man's activities. One of the better general accounts of the ecology of ponds and the smaller water bodies is that of Carpenter (1928). The biology of the water held in tree holes, leaf axils and other types of containers, although quite well known in its entomological aspects, has been completely overlooked in many reviews of freshwater ecology—those of Needham and Lloyd (1916), Welch (1935) and Hesse et al. (1951), for example. Pearce (1926) failed to notice container habitats, but the second edition (1939) of his work contains a brief section on "epiphytic waters."

The absence of an authoritative limnological classification of the smaller and more cryptic inland waters has prompted various students of mosquito biology to devise their own classification of larval habitats. Bates (1949) prepared a useful synthesis of the proposals of these entomologists.

Mosquito larval habitats do not lend themselves to the employment of the limnologists' basic division into standing and running water, as Bates indicated. Schemes put forward have thus involved the basing of the major dichotomies on such grounds as the water accumulation's source (Boyd, 1930), its location and condition (Shannon, 1931; Hopkins, 1952) and its permanence (Bates, 1949).

Bates based his own habitat analysis on the assumption that ponds and marshes represent the most generalized habitat of mosquito larvae. Pointing out the obvious analogy with the present distribution of such primitive groups as the marsupials and monotremes, he rejected as fallacious the contention of Dyar and other authors that tree holes and related container breeding places, being utilized by some of the most generalized living mosquitoes, should be recognized as the primitive type of larval habitat.

The results of the present studies provide strong support for Bates's assumption, as will be shown in the following pages. Nevertheless, although Bates's classification is better in several respects than those which preceded it, it does not exhibit the interrelationships between larval habitats to maximum advantage. Bates arranged his scheme as follows:—

A. Permanent or semi-permanent standing water.

Fresh water:

1. Large marshes or marshy zones in lakes.
2. Small ponds or marshy areas in the open.
3. Special situations such as spring-fed pools.
4. Special plant associations.
5. Special chemical conditions, such as peat bogs.
6. Swamps.
7. Forest pools.

Brackish water:

8. Brackish marshes and swamps.
9. Small accumulations of brackish water.

B. Running water:

10. Open streams in association with vegetation.
11. Open gravel stream beds.
12. Forest streams.

C. Transient ground pools:

13. Transient ground pools in the open.
14. Transient forest pools.

D. Container habitats:

15. Rock holes.
16. Tree holes.
17. Ground containers.
18. Special plant associations.
19. Crab holes.

Some of the 19 types of larval habitat defined in this list are not mutually exclusive. Thus land more or less permanently inundated with fresh water and characterized by a dominance of emergent vegetation is considered under three separate headings, 1, 2 and 6. Large marshes and small marshy areas in the open are differentiated on grounds of size, while swamps (inundated forest country) are differentiated from marshes (inundated savannah) on grounds of shade availability. Surely these differences, being ones of degree only, could be studied more effectively in their relation to one another within the limits of a single category. At the same time, such factors as the development of adaptations by mosquitoes to meet increasing specialization of larval habitats, and the matter of the routes followed in the invasion of one type of habitat from another, cannot be viewed in perspective against the background of Bates's scheme of classification.

While it is with more than a little diffidence that yet another scheme is proposed for the classification of mosquito larval habitats, it is felt that the following one is not only particularly applicable to Pacific conditions but also lends itself to the systematic study of the ecology of these water bodies:—

1. FRESH WATER.
  - A. Surface water series.
    1. Lakes and ponds.
    2. Swamps and marshes.
    3. Transient pools.
    4. Ponded streams.
    5. Flowing streams.
  - B. Container series.
    6. Large simple containers.
    7. Small simple containers.
    8. Specialized containers.
2. BRACKISH WATER.
  - C. Surface water series.
    9. Brackish lakes and ponds.
    10. Salt marshes, mangrove swamps, tidal streams and estuaries.
  - D. Container series.
    11. Simple brackish containers.
    12. Specialized brackish containers.

As already stated, the larval habitats of the great majority of mosquitoes contain fresh water. All known brackish water species—other than the unique and aberrant New Zealand *Opifex fuscus* Hutton—are recognizable as specialized representatives of large freshwater groups from which they have obviously been derived. The larvae exhibit numerous adaptations to the various waters in which their development takes place. One of the most striking of these adaptations is the universal reduction in size of the anal papillae—the chief function of which was shown by Wigglesworth (1938) to be the absorption of chlorides—which progressively accompanies any increase in the salinity of the surrounding water (this is well marked in the Pacific *Culex annulirostris*, which utilizes a wide range of both fresh and brackish larval habitats (see p. 179)). Brackish water mosquitoes having this morphological feature in common and there being fundamental faunal and floral differences between these two types of breeding places, it seems logical that the initial dichotomy should differentiate habitat types into freshwater and brackish.

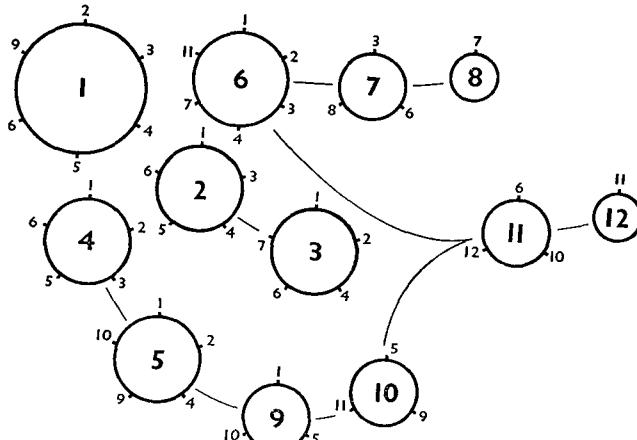
Each of the two major habitat categories is itself subdivided into two series on the grounds of the location of the water. The two surface water series are understood herein to include all types of surface water other than those enclosed in small natural basins having a nonporous lining, while the two container series should be regarded as including water held in natural or artificial containers of every kind. Waters held in small basins having a non-porous lining are held to

be referable to the latter series. "Small", as understood in respect to the size of the basins in question, defines rigid definition. The difficulty here is precisely the same as that encountered in attempts to define a line of demarcation between lakes and ponds, regarding which even such recent authors as Macan and Worthington (1951) have been forced to concede that "clearly the available data are insufficient to distinguish between lakes and ponds and we use the two words . . . with their usual rather vague meaning, implying no scientific distinction." Where criteria are a matter of degree only, decisions of this nature must be made on commonsense, rather than empirical, grounds. For example, there would be few who could disagree that a concrete drinking trough should be considered as referable to the container series, while a concrete-lined reservoir belongs to the surface water series. In exactly the same way rock holes in coral boulders and large borrow pits excavated from coral formations separate out into these two different categories. A non-porous lining is specified for the small basins in question to distinguish them from transient water bodies of equivalent size but overlying porous formations. Evaporation operates as a factor in the loss of water from both types of habitat, but those of the latter type disappear far more quickly than those of the former because their contents are continuously soaking away into the surrounding and underlying formation.

The interrelationships among the 12 proposed habitat categories are expressed in Text-fig. 2.

#### THE ECOLOGY OF MOSQUITO LARVAL HABITATS

1. LAKES AND PONDS. There are few true lakes in the tropical South Pacific, the handful that do occur there being located in old volcanic craters (e.g., Steaming Hill Lake, Gaua, Banks Group) or in the former lagoons of raised atolls. No freshwater lakes were visited, Lake Tenggano, Rennell Island, being brackish.



TEXT-FIG. 2.—Diagrammatic illustration of interrelationships among the 12 habitat categories proposed herein.

Permanent ponds are of common occurrence. Some are quite large, perhaps thirty metres or more in diameter. Here belong such natural catchments as those noted in hilltop basins over impervious formations at Tutubu (Fig. 43) and Art, and the artificial ponds formed in wartime coral borrow pits. The ponds in native taro gardens (Fig. 47) vary greatly in size. Some, like the pits dug through the water table by the Gilbertese (e.g., coll. no. 309, Tarawa), are extensive, while others are small and shallow. Trenches are commonly dug around taro beds, and when these contain pockets of stagnant seepage water or rain-water they have most of the characteristics of ponded streams. Taro irrigation systems connected with flowing streams are considered herein as referable to the latter category. The operation of such factors as area, depth, the nature of the margin and substratum, the chemical and physical characteristics of the water and the availability of shade, brings about considerable variation within category 1 habitats. There is a wide range of long-established ponds of intermediate size (Fig. 45) and there are many kinds of small seepages. The latter depend for their permanence on the level of the water table, some of them, like the Loyalty Island well illustrated in Fig. 46, being relatively permanent and others, like the Queensland roadside seepage shown in Fig. 48, not persisting far into periods of drought.

Trends away from the simple, open pond are indicated diagrammatically in Text-fig. 2. These may be in the direction of the swamp or marsh following marginal encroachment by vegetation, or in that of the transient pool in the case of seepages exhibiting relative impermanency. Then there are close biological parallels between ponded streams and simple ponds and between the latter and brackish ponds; much of the fauna and flora of brackish ponds and marshes initially invaded these habitats from freshwater lakes and large ponds by way of streams. There are also affinities between freshwater ponds and the larger simple containers—rock holes, while fundamentally containers, being a well-marked stage in the transition between permanent or semipermanent surface waters and other types of containers, as is evidenced by the intermediate nature of their faunas. A line of specialization within category 1 itself is the development of certain special floras. Although these are less evident in the Pacific than in many other areas due to the general paucity of the aquatic flora, certain water plants sometimes do achieve dominance; for example, *Eichhornia crassipes* (water hyacinth), *Lemna* spp. or *Spirodela oligorrhiza* (duckweeds, Fig. 13) and *Nymphaea* spp. (waterlilies, Fig. 14).

The salient physical features of the 70 category 1 habitats investigated may be summarized as follows:

Factor	Percentage occurrence
Availability of surface and subsurface shelter to mosquito larvae (faunal index 2 or more, filamentous algae or floatage present)	89 per cent
Positive temperature factor	83 "
Shade	73 "
Foulness	51 "

In 77 per cent. of these habitats the bottom was made up of mud, and in 21 per cent. there was a bottom covering of dead leaves and/or other organic debris. All the ponds had two main features in common, a more or less continuous water sheet (sometimes broken up marginally by emergent vegetation and centrally by floating vegetation) and relative permanency, this last factor favouring the development of a complex macrofauna and macroflora as is shown by the relevant indices:—

Faunal index	1	3	( 4 per cent.)
	2	34	(49 " "
	3	27	(39 " "
	4	6	( 9 , , )

Floral index	1	...	7	(10 per cent.)
	2	...	62	(89 " "
	3	...	1	) (1 " "
	4	...	0	)

The percentage of occurrence of the various groups of aquatic organisms was found to be as follows:—

Animals	Protozoa	....	....	....	96 per cent.
	Diptera	....	....	....	83 " "
	Odonata	....	....	....	69 " "
	Hemiptera	....	....	....	59 " "
	Coleoptera	....	....	....	46 " "
	Mollusca	....	....	....	21 " "
	Entomostreaca	....	....	....	21 " "
	Plectoptera	....	....	....	20 " "
	Arachnida	....	....	....	14 " "
	Malacostraca	....	....	....	10 " "
	Fishes	....	....	....	10 " "
	Amphibia	....	....	....	9 " "
	Rotatoria	....	....	....	7 " "
	Miscellaneous	....	....	....	13 " "
Plants	Algae	....	....	....	99 " "
	Grasses, sedges, reeds	....	....	....	57 " "
	Aquatic phanerogams	....	....	....	39 " "
	Mats or other macroscopic accumulations of filamentous algae	....	....	....	14 " "

It is proposed to consider first of all the macroscopic organisms; the mosquito larvae themselves, the animals which prey upon them or compete for their food and the plants which provide them with shelter.

As regards plants, marginal grasses, sedges and reeds were abundant at the edges of more than half of the ponds investigated throughout the area surveyed. Strictly aquatic phanerogams are more prevalent in the westerly part of the area as already noted (p. 55 ff.), where they are much more characteristic of category 1 habitats than their overall percentage of occurrence suggests. Thus 13 (93 per cent.) of the 14 records for Lemnaceae were from such habitats, as were eight (89 per cent.) of the nine records of Nymphaeace and 14 (74 per cent.) of the 19 of those for Callitrichaceae, Haloragidaceae, Marsileaceae, Menyanthaceae, Najadaceae, Pontederiaceae and Potamogetonaceae.

Mosquitoes account for the majority of the records for the Diptera, and their larvae were collected from 56 (80 per cent.) of the habitats in question. Seventeen collections of other Diptera (Tendipedidae, Stratiomyidae, Syrphidae and Tipulidae) were made from permanent and semipermanent ponds, only two of which were negative for Culicidae.

The next three orders in order of precedence, the Odonata, Hemiptera and Coleoptera, may all be regarded as characteristic of South Pacific ponds. The majority of the aquatic representatives of these orders prey upon developmental mosquitoes under laboratory conditions, and must be numbered among the most important natural enemies of mosquitoes in the habitats under consideration. Although water beetles are absent from some of the remoter oceanic islands, and aquatic hemipterans were not found in the Gilbert and Ellice Groups, the nymphs of pantropical dragonflies and damselflies were collected from category 1 habitats wherever these were studied. Representatives of all the other major groups of aquatic animals known from the area were also recorded from ponds, but none of them nearly so abundantly as the insect orders already named.

Nineteen species of mosquitoes were recorded from freshwater ponds referable to this category.—

SPECIES	NUMBER OF TIMES COLLECTED			Total
	Rare	Common	Abundant	
<i>C. annulirostris</i>	18	11	12	41
<i>An. farauti</i>	4	2	8	14
<i>C. fraudatrix</i>	6	2	1	9
<i>An. annulipes</i>	3	2	1	6
<i>An. b. bancroftii</i>	2	2	2	6
<i>A. vexans nocturnus</i>	2	1	2	5
<i>C. cylindricus</i>	1	1	1	3
<i>Ay. catalacta</i>	1	1	—	2
<i>C. halifaxi</i>	—	2	—	2
<i>C. mimulus</i>	2	—	—	2
<i>An. punctulatus</i>	1	—	—	1
<i>An. stigmaticus</i>	1	—	—	1
<i>U. atra</i>	1	—	—	1
<i>A. lineatus</i>	—	—	1	1
<i>C. basiscutus</i>	—	1	—	1
<i>C. bitaeniorhynchus</i>	—	1	—	1
<i>C. fuscipennis</i>	1	—	—	1
<i>C. squamosus</i>	—	1	—	1
<i>C. whitmorei</i>	—	1	—	1
Total	13	28	28	99

As Table XXI indicates, 13 of the 19 species concerned were collected from one to three times only. In each of these instances only one locality was concerned. *Anopheles annulipes* and *An. b. bancroftii*, which were each collected six times, were only recorded from Queensland; the former species, the dominant Australian anopheline (Lee and Woodhill, 1944) was collected from 18 other larval habitats (categories 2, 3, 4, 5), while the latter one, which according to Roberts (1948) favours "the more permanent still waters, thickly covered with vegetation . . ." was found in only two other places (categories 4 and 5).

*Aedes vexans nocturnus* was recorded five times, this widely distributed mosquito being taken from ponds at Aitutaki, Tongatabu, Upolu, Tarawa and Funafuti. It was also collected from 10 other habitats (categories 3 and 4) and is best known as a transient pool breeder.

*Culex fraudatrix*, collected from six permanent ponds at Tutuba and three in Queensland, was present in 12 additional samples referable to categories 4, 5, 6, 7 and 11. This species, although of rather catholic breeding habits, thus appears to exhibit a preference for the habitat under consideration.

The 14 collections of *Anopheles farauti* originated from Queensland (7), Aincitymu (1), Sikaiana (2) and Espiritu Santo (1). Forty-four other collections included this anopheline, which was rather more plentiful in transient pools and ponded ditches than in permanent ponds and also occurred in swamps, streams, brackish ponds and estuaries and (rarely) in containers.

Throughout the area investigated the characteristic permanent pond mosquito was *Culex annulirostris*. This species was collected 41 times from such habitats in every island group visited with the exception of the Tokelau Islands where it is unknown. Its percentage of occurrence in these (59 per cent.) was only exceeded by that for freshwater swamps and marshes (80 per cent.), being closely followed by the figures for brackish ponds (56 per cent.) and marshes (44 per cent.). *C. annulirostris* was also found plentifully in transient pools and ponded streams and less commonly in flowing streams and containers.

As regards larval associations in permanent ponds, 28 (50 per cent.) of the collections, only one of these from Queensland, included but a single species of mosquito. Nineteen (34 per cent.) included two species, these and the single records embracing all of the insular samples with the exception of one from Sikaiana in which three species were represented. The remaining eight collections, in each of which from three to five species occurred, all originated from Queensland. These

comprised 50 per cent. of the relevant Queensland larval samples. The decreasing utilization of the habitat by mosquitoes in a west-east direction is thus well marked.

A feature of the mosquito collections from permanent and semi-permanent ponds is the tendency towards larval scarcity—the total number of species' records was 99, larvae being listed as rare in 13 of these and merely common in a further 28. These figures are interpreted as reflecting the influence of competition and predation.

The decreasing utilization of category 1 habitats by mosquitoes as one moves out into the Pacific from Australasia is, as already demonstrated, accompanied by a steady decrease in the representation of aquatic phanerogams and animals. Various families of insects which include mosquito predators drop out one by one—the Nepidae and Naucoridae (Hemiptera) in Queensland, *Lutziinae* (Culicidae) in the Solomons, the Belostomatidae, Corixidae and Hydrophilidae (Hemiptera) in New Caledonia, the Pleidae (Hemiptera) in the New Hebrides, the Gyrinidae (Coleoptera) in Fiji and the Baeidae (Plecoptera)<sup>1</sup> in Samoa. At the same time, the species representation of the remaining groups becomes steadily smaller as the distance eastwards increases, and the associations of species in individual ponds become steadily less complex. Thus in the Coleoptera—the only order other than the Diptera in which the Pacific species are well enough known for most of the material to be specifically determined at the present time—more than two species were recorded from the same pond on only one occasion (3 species, coll. no. 48, Art) in the 20 relevant collections made in the Pacific islands, but seven of the 12 pond collections in which beetles figured in Queensland included from three to five species.

However, a number of mosquito predators which inhabit permanent and semi-permanent ponds still remain even as far eastwards as the Society Islands, the Tuamoto Group and the Marquesas. These include decapods, water beetles (Dytiscidae, Palpicornia), hemipterans (Gerridae, Notonectidae, Veliidae), pond spiders (Pisauridae) and various small fishes both native and introduced. Inter-specific competition being less intensive than in Melanesia or Queensland, the lack of variety within these various groups of animals is frequently accompanied by an unusual abundance of individuals of the species present. Time unfortunately did not permit of a quantitative study of aquatic populations, but my field notes indicate that dragonfly nymphs were sometimes remarkably plentiful in ponds in Tonga (coll. no. 46<sup>1</sup>), Aitutaki (coll. no. 20<sup>1</sup>), and Tarawa (coll. nos. 310, 57<sup>1</sup>). Similar observations were made in respect of the tadpoles of the introduced toad *Bufo marinus* in Viti Levu (coll. no. 38<sup>1</sup>) and Fumafuti (coll. no. 60<sup>1</sup>), and of the introduced "millions fish" *Lebiasina reticulata* at Aitutaki (coll. no. 122), while hemipterans, *Microclelia samoana*, *Limnognathus* sp. and *Anisops* sp. were extremely abundant in a well in Upolu, Samoa (coll. no. 21<sup>1</sup>). As already noted, the large ostracod *Stenocypris macleholmseni* was present in very great numbers at the edges of a large pond (coll. no. 121) in Aitutaki. Developing mosquitoes, although faced with a less complex association of natural enemies in category 1 habitats in Polynesia than in Melanesia and Queensland, thus still have to contend with a considerable degree of food competition and predation while at the same time having generally less shelter from the attacks of their enemies because of the paucity of the aquatic flora which characterizes the area. The west-east decrease in the number of species of mosquitoes and other animals which utilize category 1 habitats is not, therefore, accompanied by any obvious increase in mosquito production from these habitats. This is evidenced by the facts that larvae were altogether absent from six (32 per cent.) of the 19 such water bodies examined in the island groups to the east of Fiji and that in the remainder six (38 per cent.) of the 16 species' records were registered as abundant, six as common and four (25 per cent.) as rare.

The overall percentage of category 1 ponds altogether lacking in mosquito larvae, 20 per cent., is not significantly higher than the percentage (19 per cent.) for water bodies of all types. In some cases (e.g. Funafuti, coll. no. 59<sup>1</sup>) the conditions seemed perfectly favourable for local mosquito species and no explanation can be proposed for the absence of larvae. In others (e.g. Viti Levu, 1<sup>1</sup>; Upolu, 21<sup>1</sup>) a combination of relatively deep water, steep banks, little vegetational shelter and an abundance of other animals including numerous predators had erected a formidable barrier to the establishment of mosquitoes. It is considered that long-established and naturally balanced ponds of the latter type should not be heedlessly larvicated in mosquito control programmes. Whether or not they should prove to act as mosquito traps in consequence of adults habitually ovipositing upon them despite the unfavourable conditions for larval development, the elimination of the balanced macrofauna which would result from chemical control measures would leave such ponds open to invasion by mosquitoes following any interruption to the larvicidal programme (Laird, 1952). Where there is any doubt as to whether or not a permanent pond is producing mosquitoes, and where its elimination by drainage or filling is undesirable or impracticable, the augmentation of its fauna with larvicidal fish or other proved predators and the regular clearance of any vegetation present affords a more realistic approach to control.

Hopkins (1952) assumed that the typical mosquito larva is one which breeds in places of the "ground pool" type, which obtains its food by ingesting micro-organisms swept into its mouth by the action of the inouth brushes and which derives at least the major portion of its supply of oxygen from the air at the surface of the water. Among the mosquitoes utilizing category 1 habitats the chief modifications are associated with habits, not with the habitat. Thus *Ficalbia*, *Aëdomyia* and *Mansonia* all display associations with vascular plants from which all (in the case of members of the latter genus) or part of their air supply is obtained. The relevant morphological modifications involve specializations of the antennae, of the siphonal valves and of the siphon itself. Hopkins quoted Muspratt for the information that certain members of the subgenus (*Culex*) have bladder-like organs—as does *Aëdomyia*—on the underside of the larval head. These organs have a rich tracheal supply, and Muspratt suggested that they may be an oxygen-absorbing apparatus, pointing out that the larvae concerned are able to remain submerged for long periods. Lewis (1949) associated the development of such head bladders, and of prominent superficial tracheoles in this location in other *Culex* larvae, with the acquisition of the habit of feeding on the bottom for extended periods. He, too, considered these organs to have a respiratory function.

The representatives of the *bitaeniorhynchus* complex of *Culex* (*Culex*) encountered during these studies—*C. bitaeniorhynchus*, *C. basincinctus*, *C. squamosus* and *C. allinervis*—all exhibit well marked tracheation of the head. These larvae feed all but exclusively on filamentous green algae in nature and often remain submerged amongst algal masses for periods of 15 minutes and upwards. Although the first three species figured among the pond collections the *bitaeniorhynchus* complex is more closely associated with flowing and ponded streams, the clean water of which favours prolific development of the algal genera concerned, *Spirogyra*, *Mougeotia* and *Zygnema*. With these three exceptions, and that of the predaceous larvae of *Culex halifaxi*, none of the larvae listed in Table XXI were found to have selective feeding habits.

It is generally accepted to-day that most mosquito larvae are unselective in their feeding habits, ingesting any material sucked into the feeding vortex set up by the mouth brushes which is small enough to be taken in through the mouth (Hinman, 1930). The contents of the gut thus include a representative selection of the micro-organisms and small organic and inorganic particles present in those parts of the habitat where the particular larva concerned feeds (Coggeshall, 1926;

Howland, 1930). The concentration of particular micro-organisms in the gut, however, does not necessarily reflect the abundance of these in the feeding zones in general. Such organisms may be abundant in the gut contents although rare in the feeding zone from which the larva in question was collected either in consequence of previous browsing in a part of the habitat where they were common or of their being filtered from the relatively large volume of water passed through the larval body during a period of intensive feeding (Howland, 1930).

The mere presence of micro-organisms in the larval gut by no means implies that these are utilized as food. Fungal spores, for example, may pass through the gut unchanged and germinate on appropriate media (Batschinsky, 1927). Authors differ as to the role of diatoms as a larval food. Some workers, such as Senior-White (1928), have contended that these algae are an important source of larval nutrition, while others, such as Himmelman (1930), who stated that "it is extremely doubtful if the digestive juices of the larvae would have any solvent action on these hard silicious shells", have expressed strong doubts as to their value as digestible food. Goldacre (1919) has pointed out that the protein or lipo-protein monolayer of surface films can in itself constitute a significant portion of the diet of aquatic animals. Trager (1935) reared larvae in the absence of living micro-organisms.

As already noted unicellular algae, primarily diatoms, were present in all the category 1 habitats studied. Ninety-six per cent. of the latter were positive for Protozoa, mostly small holotrichous or spirotrichous ciliates, and a lengthier examination would doubtless have revealed the presence of representatives of this phylum in the remaining four per cent. Diatoms were always recognizable amongst the amorphous material and angular inorganic particles which usually constituted the greater part of the gut contents of pond larvae other than the selective feeders already mentioned. Whenever easily recognizable unicellular algae—such as *Scenedesmus quadricauda* (coll. no. 17)—or protozoans reasonably resistant to the digestive juices such as *Phacus* spp. (coll. no. 117, etc.) or *Pandorina morum* (coll. no. 330) were plentiful in the water they were also plentiful in the alimentary tract of the mosquito larvae present. Other organisms recognized in the gut of pond larvae included fungal spores (71 per cent. of all species/collections) and pollen grains (37 per cent. of all species/collections), and fragments of filamentous algae, plant tissues and insect hairs and scales frequently came under notice. It is not felt that the detailed listing of the findings from gut dissections would serve any useful purpose, for these afford no data not already apparent from such lists published by numerous earlier investigators.

It was initially expected that dissections might reveal marked differences in the materials ingested by *Anopheles farauti* and *Culex annulirostris* larvae when occupying their respective ecological niches in the same habitat. However, despite the facts that anopheline larvae are generally regarded as surface feeders and culicines as subsurface and bottom feeders, no such differences were apparent from the data accumulated. The selfsame organisms and organic and inorganic debris were found to have been ingested by larvae of both *An. farauti* and *C. annulirostris* sharing the same ponds, the proportions of the various materials present varying within each species and not exhibiting significant differences as between the two species. My wife supplied the explanation for this after a lengthy observation of the behaviour of larval *An. farauti* in a pond at Ancityum. She noticed that although when these larvae are disturbed they drop from the surface and remain inactive at the bottom until compelled to come up for air, if they are allowed to remain undisturbed they indulge in considerable voluntary underwater activity. While they undoubtedly spend a significant portion of their time feeding at the surface film, they often spend as much time browsing among submerged algae and other plants and along the bottom itself. An earlier observation to the same effect was subsequently happened upon, Senior-White (1928) having remarked with regard to (*Anopheles rufi*) = *An. subpictus* Grassi in-

India that larvae, despite the presence of abundant micro-organisms at the surface of the water in a laboratory container "did a lot of browsing at the bottom, though they had to descend quite four inches to reach it, and there was nothing particular there for them when they did." *C. annulirostris* larvae, on the other hand, frequently arch the forepart of the body upwards while the siphon is applied to the surface film; and, while revolving about the point of application of the siphon, actively ingest material from the surface itself.

Some observations were made with regard to evidence of digestion exhibited by micro-organisms dissected out from the alimentary tract of larvae. Comparisons of the foregut and hindgut contents of various species of larvae indicated that browsing at the bottom commonly leads to the ingestion of the empty shells of diatoms, and that diatoms ingested in the living state frequently pass right through the gut with the chloroplast intact. Degenerative changes are apparent, though, in most of the thinner-walled algae and in phytoplasmellates. Freshly ingested examples of species of *Phacus*, *Tachyomonas* and *Euglena* often still exhibited active movement among the foregut contents, although they had usually already lost the free flagellum when dissected out. Specimens from the midgut showed evidence of digestion in the degeneration of the chromatophores (Figs. 36 and 37), while those from the hindgut were often mere empty shells or contained only tattered remnants of the chromatophores (Fig. 35). The striated pellicle of *Phacus* is sufficiently resistant to the gut juices to preserve its characteristic shape to the last and identifiable portions of other relatively robust protozoans were also noticed (e.g., *Coleps* sp., Fig. 39). The ingestion of the fragile ciliates *Pleuronema* sp. (Fig. 10) and *Homalozavra* sp. (Fig. 41) was observed by the use of a live-box, but dissections made within five minutes failed to reveal the presence of these protozoans in a recognizable state among the foregut contents. Such ciliates being common and widely distributed in pond water it is certain that they form a substantial part of the material ingested by mosquito larvae in nature, the extreme delicacy of their pellicle resulting in their early becoming unrecognizable; it is equally certain that they are utilized as food, although leaving no traces to be discovered in an examination of the gut contents. Larvae having heavy infestations of voricellids about the terminal abdominal segments are often observed to bend the body in an arc and apply the mouthparts to the protozoans. Rounded up but still rather active examples of these ciliates may be dissected out from the anterior part of the alimentary tract of such larvae. One specimen of *Vorticella microstoma* found in the foregut of an *An. farauti* larva was still able to move right across a low power field by means of its adoral cilia. These ciliates, though, were always dead and shapeless by the time they had reached the posterior part of the gut, and phase contrast examination of fresh material revealed that the cytoplasm and macronucleus had undergone gross degenerative changes. Larvae known to have ingested voricellids were preserved in formalin, but the ciliates could not be detected on subsequent microscopical examination.

It is therefore considered that although many of the thicker-walled living objects, such as fungal spores and many diatoms, ingested by larvae pass through the gut unchanged, the more delicate micro-organisms present in pond water furnish readily available larval food. Without prejudice to the view expressed by Hinman (1930) and others to the effect that inorganic and organic substances in solution and colloids in suspension furnish a large part of the nutritive material utilized by larvae, or to the fact that necessary accessory growth factors may be supplied by common pond water bacteria such as *Bacillus subtilis* (Buddington, 1941), it is submitted that protozoans, notably those lacking a resistant pellicle, are of much more significance as mosquito larval food than the infrequency of their detection in gut contents would suggest.

It is perhaps worthy of mention in regard to the specialist feeders of the *bitaeniorhynchus* group of *Culex* that doubts have been expressed as to the invariable

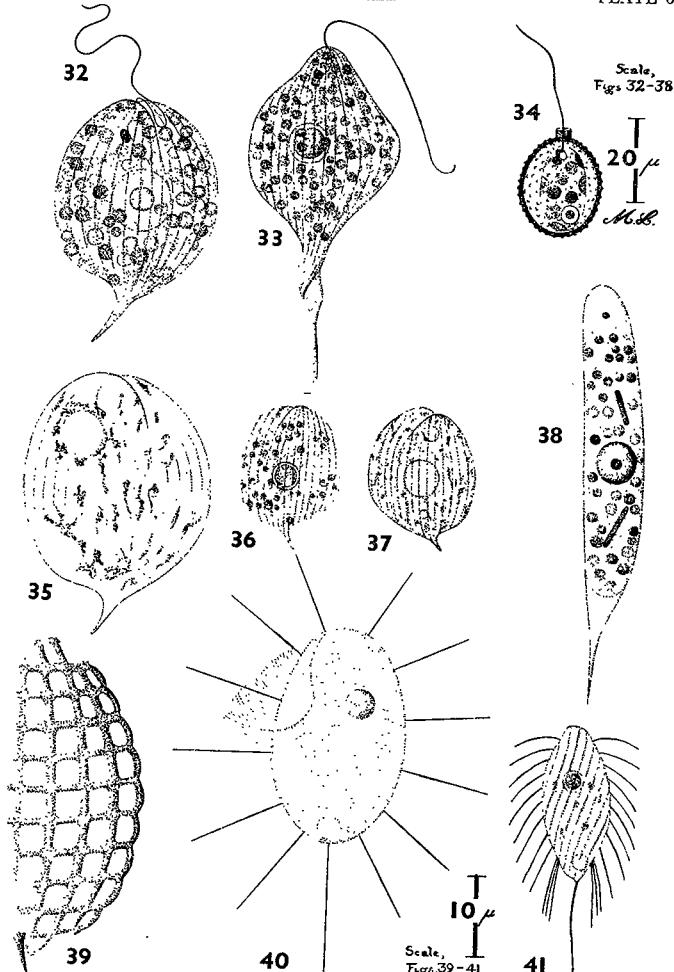


FIG. 32.—*Phacus pleuronectes* (Müller) (coll. no. 17). From life. 880 X. FIG. 33.—*Phacus longicaudus* (Ehrenberg) (coll. no. 302). From life. 880 X. FIG. 34.—*Trachelomonas hispida* (Perty) (coll. no. 1<sup>1</sup>). From life. 880 X. FIGS. 35-37.—*P. pleuronectes* from the alimentary tract of mosquito larvae. From life. 880 X. FIG. 35.—Example in advanced state of degeneration from the hind gut of *Anopheles farauti* (coll. no. 274). FIGS. 36 and 37.—Examples from the mid gut of *An. farauti* (coll. nos. 17 and 271 respectively). FIG. 38.—*Euglena* sp. from mid gut of *An. farauti* (coll. no. 274). From life. 880 X. FIG. 39.—Portion of the exoskeleton of a species of *Coleps*, from the hind gut of *Culex annulirostris* (coll. no. 17). From life. 1,700 X. FIG. 40.—*Pleuronema* sp. (coll. no. 17). From life. 1,700 X. FIG. 41.—*Homologastra* sp. (coll. no. 3<sup>1</sup>). From life. 1,700 X.

association of such larvae with filamentous green algae and as to the food value of these algae. Williamson (1928) stated that Senior-White's claim that *C. bitaeniorhynchus* larvae are always associated with *Spirogyra* "is certainly an exceptional phenomenon; and no such association can be accepted as invariable unless it has been proved over a wide area, embracing diversified types of water." Williamson himself (1935) subsequently confirmed the observation in respect of Malaya, and the three collections made in New Caledonia and Queensland were all from *Spirogyra*. As regards the other species of the *bitaeniorhynchus* complex encountered, 10 of the 11 collections of *C. basicinetus* larvae in New Caledonia, the New Hebrides and Queensland were from *Spirogyra* masses, the remaining one being from a related algae of the same family, *Zygnuma gorakhporensis*. Two of the four collections of the Fijian *C. albinceris* were from *Spirogyra* and two from masses of another member of the Zygnemataceae, *Mougeotia* sp. Finally, *C. squamosus* was taken amongst *Spirogyra* masses on nine occasions in Queensland and the Solomons. On the only other occasion upon which this last mosquito was recorded its larvae were found in a transient pool devoid of filamentous algae (coll. no. 271, Guadalcanal). Bich (1951) sometimes collected *C. squamosus* in New Guinea in habitats lacking vegetation, but nevertheless stated that the species typically frequents dense masses of algae flourishing in sunlight. It is apparent, therefore, that the association of larvae of the *bitaeniorhynchus* complex with masses of filamentous green algae belonging to the Zygnemataceae is, if not absolute, certainly customary. Hinman (1930) pointed out that when filamentous algae are at all abundant in larval habitats they occur in varying amounts in the gut contents of any mosquito larvae present. He stated that it is usually impossible to detect any difference in the appearance of portions of ingested filaments in the fore- or hind part of the intestine, and that the faeces frequently contain cells apparently unchanged, concluding that "it is very doubtful if filamentous green algae are of any considerable nutritive value to Culicid larvae." This is certainly not so in respect of the *bitaeniorhynchus* complex, for the alimentary tract of all the larvae collected (with the exception, of course, of those of *C. squamosus* from coll. no. 174) was invariably crammed with chewed-off lengths of algal filaments of about 300 $\mu$  in length, the chloroplast of the cells in the foregut being intact and that of the cells in the hindgut and faeces being ragged and degenerate if not altogether absent. Diatoms and other micro-organisms were sometimes present in the gut contents as well, but these were always associated with the algal masses concerned and had presumably been ingested incidentally while the larvae were browsing on algal filaments.

Second instar larvae of *C. basicinetus* collected from submerged *Spirogyra* masses on Espiritu Santo were reared to maturity in the field laboratory in a jar containing a litre of water and bottom debris from a permanent pond (coll. no. 17). They developed perfectly well in the complete absence of *Spirogyra*, the gut of fourth instar larvae being found to contain quantities of amorphous material together with diatoms, fungal spores and phytoplankton as did that of larval *Anopheles farauti* and *Culex annulirostris* occurring naturally in the pond whence the water was derived. From this experiment and from the natural occurrence of *C. squamosus* from time to time in water lacking filamentous green algae it is obvious that the latter is not an essential food for these larvae. It is thought most probable that the association of larvae of the *bitaeniorhynchus* group with submerged masses of Zygnemataceae initially came about because of the shelter to be derived there from the attacks of free-swimming predators. Mohan (1950) observed in India that *C. bitaeniorhynchus* females kept in the laboratory only oviposit when "green algal growth" is introduced into their bowls. In whatever manner the selection of the larval niche is made in nature it is considered that the unusual feeding habits of the larvae of these mosquitoes are an adaptation to the food potential of that niche rather than the primary reason for its occupancy.

*Aedomyia catasticta* is another mosquito the larvae of which are frequently found secreted amongst underwater vegetation. Others have found that this species is particularly common in association with *Nitella*, while we collected larvae from submerged *Najas tenuifolia* and from *Spirogyra* masses. Although the niche occupied by larval *Ay. catasticta* is not as specific as in the case of the *bitaeniorhynchus* group, the same advantage of protection from predators applies. All these larvae, as already observed, exhibit rich superficial tracheation of the head which is regarded as enabling them to assimilate some of the oxygen given off in photosynthesis by green plants amongst which they are customarily found. For this reason they are able to remain submerged for much longer periods than is customary for free-living larvae. Needing to visit the surface for air only occasionally they are not only able to take full advantage of the shelter provided by their ecological niche but they spend a minimal amount of time exposed to the attacks of predators in the unobstructed water between the niche and the surface.

**2. SWAMPS AND MARSHES.** Bates (1949) defined marshes as extensive areas of inundated open country or savannah, considering that most marshes represent a stage in lake succession where shoal conditions permit the general growth of vegetation. He lumped small marshy areas in the open together with small ponds and ponded ditches. It is not considered herein that the limitation of "extensive" should be retained in the definition of this type of water body, for small marshy areas are ecologically comparable with large ones whether they are stages in pond—rather than lake succession or merely seepage-fed areas in places where there is no evidence that either lakes or ponds ever existed. The ten studied ranged from marshy tracts at the edges of large permanent ponds through marshy ground in which a shallow water sheet was broken up into a complex of small pools to the more usual seepage-fed areas quite choked by emergent vegetation.

Only one true swamp was happened upon, this (coll. no. 73, Aneityum) being illustrated in Fig. 49. The biotope is closely comparable with that of marshes characterized by the "erect naked" type of emergent vegetation, but shade is usually more pronounced because of the canopy of inundated forest. True freshwater swamps, of common occurrence in many parts of the world, are relatively rare in the islands of the South Pacific. Throughout the area, though, the term "swamp" is loosely applied to cover all types of inundated country whether the water concerned is fresh or brackish.

Swamps and marshes are set apart from lakes and ponds by the broken up nature of the water sheet which, particularly in the case of the less extensive marshes, is usually replaced by numerous small to very small shallow pools closely adjacent to one another and separated by mounds of waterlogged earth. The dominance of emergent vegetation differentiates these from otherwise similar habitats within category 1, while this same factor, taken in conjunction with their relative permanence, distinguishes them from transient pools (category 3). Small pools throughout areas of muddy ground trampled by animals and which are above the normal level of the water table and lacking in vegetation, dry up rapidly following rain. These (Fig. 50) are regarded herein as transient pools, their resemblance to marshes being only superficial. Ponded ditches, especially those accessible to stock, frequently present the appearance of a marsh in miniature (Fig. 52). Such habitats also lack the permanence of marshes, being flushed out by rain, and they are best looked upon as ponded streams (category 4) with which their biology has most in common. Insofar as streams flow into marshes on occasion there may be faunal and floral links with this type of habitat (category 5), while small, marginal marsh pools may be invaded by animals more usually found in container habitats or transient pools. These various relationships are indicated diagrammatically in Text-fig. 2.

The permanency of swamps and marshes, like that of lakes and ponds, is reflected in the development of a complex macrofauna and macroflora. The totals and percentages of the respective indices for the eleven dealt with are as follows.—

Faunal index	1	—	—	—	0
	2	—	—	9	(82 per cent.)
	3	—	—	2	(18 " "
	4	—	—	0	)
Floral index	1	—	—	0	
	2	—	—	11	(100 " "
	3	—	—	0	)
	4	—	—	0	

The percentage of occurrence of the various groups of aquatic organisms was found to be as follows.—

Animals	Protozoa	—	—	—	—	91 per cent.
	Diptera	—	—	—	—	91 "
	Hemiptera	—	—	—	—	55 "
	Coleoptera	—	—	—	—	45 "
	Odonata	—	—	—	—	36 "
	Fishes	—	—	—	—	27 "
	Amphibia	—	—	—	—	27 "
	Mollusca	—	—	—	—	18 "
	Entomostraca	—	—	—	—	18 "
	Malacostraca	—	—	—	—	9 "
Plants	Microscopic algae	—	—	—	—	100 "
	Grasses, sedges, reeds	—	—	—	—	100 "
	Aquatic phanerogams	—	—	—	—	18 "
	Macroscopic accumulations of filamentous algae	—	—	—	—	18 "

Mosquitoes again account for the dominance of the Diptera over other macroscopic animals. They were collected from all 10 habitats in which the order was represented, while larval Tendipedidae were recorded twice. Only four species were encountered.—

TABLE XXII

SPECIES		NUMBER OF TIMES COLLECTED			Total
		Rare	Common	Abundant	
<i>C. annulirostris</i>	.. .	4	2	3	9
<i>An. formosus</i>	.. .	1	1	1	3
<i>A. lineatus</i>	.. .	—	1	1	2
<i>An. annulipes</i>	.. .	—	1	—	1
Totals	.. .	5	5	5	15

As Table XXII indicates, the outstanding feature of the mosquito fauna of these habitats is the dominance of *Culex annulirostris*, larvae of this species being found in nine of the 10 collecting stations from which Culicidae were recorded, in Queensland, the New Hebrides (Aore and Aneityum), Fiji, Samoa and Aitutaki.

The next most abundant orders are, as in category 1, the Hemiptera, Coleoptera and Odonata. The percentage of occurrence of the two first-named orders is virtually the same as in ponds, but that of the Odonata is much less (36 per cent. as compared with 69 per cent.). Fishes and amphibians occupy a higher place in the list, while the percentage of occurrence of the Mollusca, Entomostraca and Malacostraca is comparable. It is considered unlikely that any of these differences have real significance, the figures for swamps and marshes being based on only 11 as compared with 70 collections. In all probability a wider range of collections would have resulted in the recording of representatives of the other groups listed from category 1 but not category 2 habitats.

The only point of real difference is held to be in the matter of the macroflora, all of the category 2 habitats having abundant emergent vegetation throughout, and some of them supporting strictly aquatic phanerogams and algal mats as well. Despite the fact that abundant and varied predators occur the rarity of larvae appears to be less marked than in ponds, as might be expected from the better facilities for shelter provided by the more prolific vegetation.

The availability of micro-organisms suitable as mosquito larval food is as marked as in category 1 habitats. As regards adaptations to this biotope, freshwater marshes and swamps are the customary habitat of the developmental stages of the subgenus *Coquillettidia* of *Mansonia*. These are very difficult to locate, and were neither collected nor specially searched for at any length during the project. The subgenus occurs in Australia, the Solomons, New Caledonia, the New Hebrides and Fiji. All *Mansonia* larvae and pupae derive their air supply from the roots of aquatic plants, the former by means of a saw-like modification of the siphon and the latter by means of the spine-like respiratory trumpets. According to Edwards (1932) the developmental stages of *Coquillettidia* are always found in the mud about the roots of emergent grasses, bulrushes and other plants, remaining submerged until the time of emergence. Lever (1943b) collected *Coquillettidia* larvae from the roots of marsh sedges in Fiji, while Perry (1949) recorded them from the underwater parts of soft-rooted dwarf *Pandanus* in the New Hebrides. As in the *bitaeniorhynchus* group we have here an adaptation which safeguards the larvae from predators to a large extent. Mosquito larvae are, in general, most vulnerable to predation whilst actively moving about in unobstructed water within the field of perception of free swimming natural enemies, either in the course of feeding or in process of travelling to and from the surface. Respiratory adaptations which render visits to the surface less frequent—as in the *bitaeniorhynchus* complex—or which do away with the necessity for such visits altogether—as in *Coquillettidia*—and which at the same time involve the maximal use of the available plant cover, obviously favour the chances of survival of the larvae concerned.

3. TRANSIENT POOLS. These are defined as accumulations of water in relatively shallow hollows which do not intersect the water table. They are usually filled by rain only, although where they are located in the flood plains of rivers they may be filled by overflow during periods of heavy flooding. Whenever they occur, such pools tend to be formed synchronously and in great numbers. Thus those resulting from the melting of ice at the spring thaw cause annual plagues of pest mosquitoes in arctic and subarctic North America (West, 1951), while in the Pacific shallow hollows which fill with water from time to time during the rainy season are likewise responsible for great increases in the mosquito population. The rain itself tends to flush out larvae from some such pools, but within a few days each replenished transient pool is likely to be supporting huge numbers of larvae (Laird, 1946a).

Transient pools are short-lived, some, like the ephemeral rain puddles described by Levander (1900), drying up in one or two days, while others last for perhaps a week or ten days. Their water both soaks away into the ground and evaporates between periods of rain. Because of this, they are characterized by a dearth of vegetation and a poorly developed macrofauna. This latter point is of decided significance, for those mosquitoes which can pass through their larval and pupal stages swiftly enough to utilize them as breeding places and can—in the case of pools in open places— withstand the high degree of exposure to sunlight consequent upon the usual lack of sheltering vegetation, have the advantage of developing in the presence of far fewer predators than dwell in the permanent and semi-permanent larval habitats discussed thus far. This freedom from molestation favours the development of heavy mosquito populations up to the limits of the available food supply.

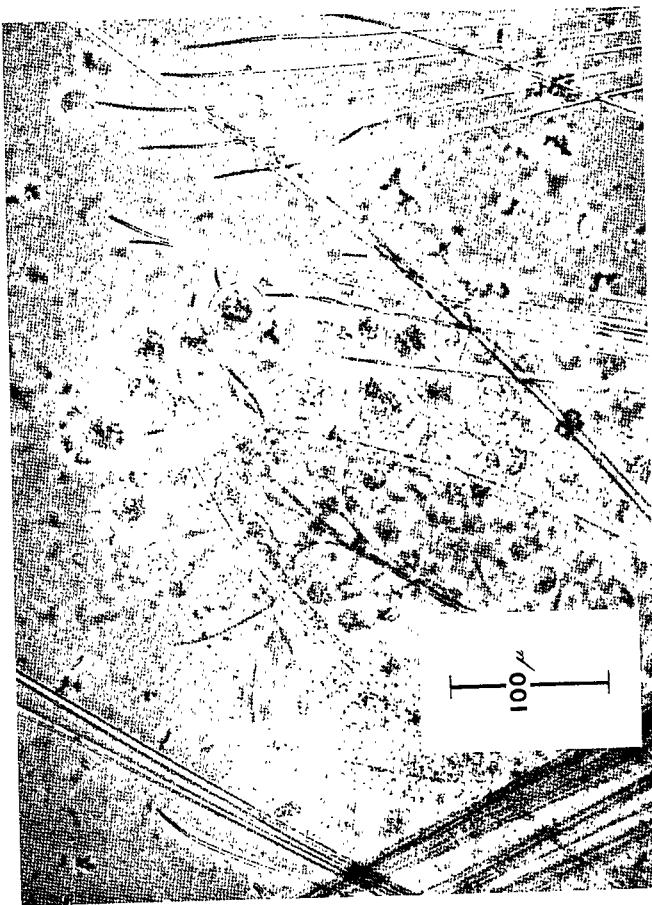


FIG. 12.—*Ixodes microstoma* Ehreben on anal papilla of *Culex pipiens latigenus* (coll. no. 1). Note transverse macromuculus of topmost example. Photomicrograph from life. E. A. Ladd. 315 X

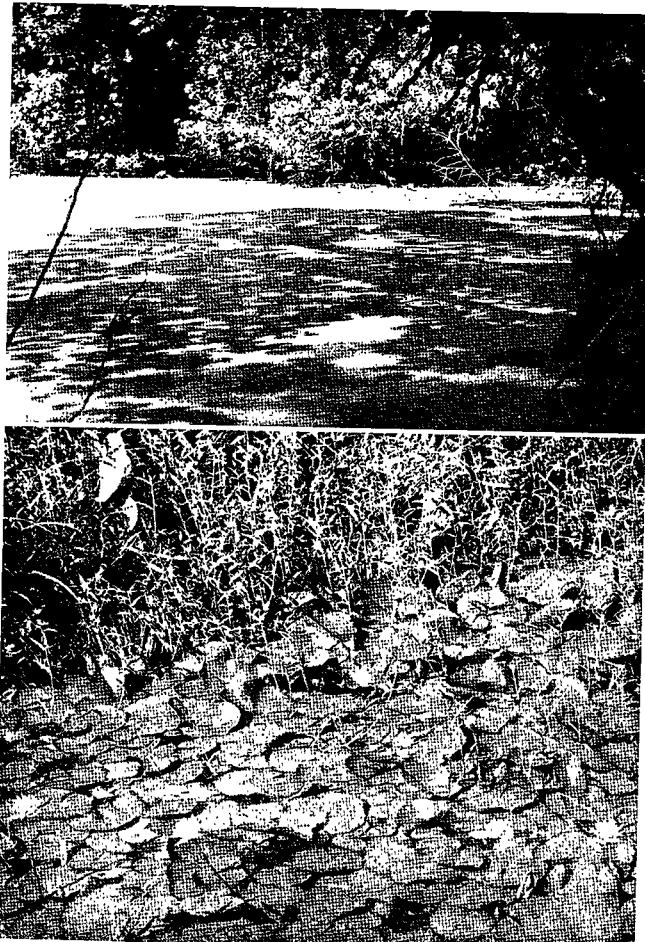


FIG. 13.- Forest pond, Utituba (coll. no. 31), Category I. The entire surface covered with a pleuston of duckweed, *Spirodela oligorrhiza*. Note heavy shadows cast by overhanging trees and fallen leaves lying on the duckweed carpet. Mosquitoes absent. Photo., E. A. Laird. FIG. 14.- Pond in taro garden, Aitutaki (coll. no. 122), Category I. Floating leaf cover of water lilies, *Nymphaea* sp. *Culex melanostomus* present but rare.

Fifty-one transient pools, seven (11 per cent.) of which lacked developing mosquitoes, were studied in Queensland, the Solomons, Arf (Belep Islands), the New Hebrides, Fiji, Samoa and the Gilbert and Ellice Groups. Only three such pools were seen in Queensland, two on Espiritu Santo and none at all in New Caledonia, the visits to these places all being made during seasons of little rainfall. Twenty were studied at Guadaleanal, the coastal field work there being undertaken during unsettled weather. Most of the transient pools dealt with were located in hoofprints (e.g., coll. no. 200, Guadaleanal; Fig. 50) or wheel ruts, while others were in slight irregularities of the ground (e.g., coll. no. 47, Arf). Those seen at Tarawa (coll. no. 304) and Funafuti (coll. nos. 58<sup>1</sup>, 311, 66<sup>1</sup>) were in taro pits which normally would have intersected the water table, but which held only small amounts of water due to recent light rainfall in the midst of a prolonged dry spell. During this period the level of the water table had fallen below that of the floor of the pits.

The following is a summary of the salient physical features of the transient pools studied.—

Factor	Percentage occurrence
Positive temperature factor	85 per cent.
Shade	67 "
Foulness	63 "
Availability of shelter to mosquito larvae	18 "

Eighty-two per cent. of the pools were mud-bottomed, the remaining 18 per cent. having a bottom covering of dead leaves. Rather more of them contained decomposing material of animal origin than was the case in category 1 habitats, 51 per cent. of which had been polluted by animals. The temperature and shade factors were comparable for the two habitats, the majority of those in both categories receiving sufficient sunlight for the water temperature to rise above the air temperature during the day. The most striking difference concerns the availability of shelter to mosquito larvae. Phanerogams, filamentous algae or floatage afforded such shelter in 89 per cent. of the category 1 habitats, the figure of only 18 per cent. for this factor as regards transient pools drawing attention to the very marked lack of vegetation in these.

The macrofauna as well as the macroflora of transient pools is very poor by comparison with category 1 and 2 habitats, as is evident from the relevant faunal and floral indices and the percentage occurrence of the individual groups recorded.—

Faunal index	1	14	(27 per cent.)
	2	37	(73 " "
	3	0	
	4	0	
Floral index	1	43	(84 " "
	2	8	(16 " "
	3	0	
	4	0	
Animals	Diptera	.....	90 per cent.
	Protozoa	.....	65 " "
	Hemiptera	.....	35 " "
	Odonata	.....	20 " "
	Entomostraca	.....	16 " "
	Coleoptera	.....	12 " "
	Mollusca	.....	6 " "
	Amphibia	.....	6 " "
	Malacostraca	.....	4 " "
	Plecoptera	.....	2 " "

	Rotatoria	..	..	..	..	2	"	"
	Miscellaneous	..	..	..	..	4	"	"
Plants	Microscopic algae	..	..	..	..	31	"	"
	Grasses, sedges, reeds	..	..	..	..	10	"	"
	Macroscopic accumulations of filamentous algae	..	..	..	..	4	"	"

Mosquito larvae were present in 86 per cent. of the pools, one of the seven negative for Culicidae supporting larval chironomids (coll. no. 17<sup>1</sup>) and another larval heleids (coll. no. 76<sup>1</sup>). The only other Diptera recorded were referable to the Tipulidae, this family, like the Heleidae, being noted once only. The Tendipedidae, however, were represented by the genera *Tendipes* and *Pentaneura* in 11 collections, 20 per cent. of the total, larvae belonging to the former genus dominating the fauna of one pool (coll. no. 17<sup>1</sup>) to such an extent as to probably account for the absence of culicid larvae (p. 89).

The data for the various other groups lend themselves to comparison with those from category 1 habitats, a relatively large number of transient pools having come under notice (51, 11 per cent. of all the water bodies dealt with).

Hemipterans were of quite common occurrence, but the families more closely committed to aquatic habits were rare. Representatives of the genera *Microvelia* (Veliidae), *Limnogonus* (Gerridae), *Mesovelia* (Mesovelidae) and *Anisops* (Notonectidae) were recorded, the first-named genus accounting for 16 of the 23 species/records. The percentage occurrence figure for the Veliidae, 31 per cent., is close to that for this family from category 1 habitats, 34 per cent.; while the relevant figures for the more strictly aquatic Notonectidae are 4 per cent. and 21 per cent. respectively.

Odonata were of much less common occurrence in transient pools than in permanent ones, being present in only 20 per cent. of the former as compared with 69 per cent. of the latter. Those found were always of small size and in the earlier instars, and they were only recorded from pools which, having a relatively complex fauna, had obviously been established for some little time and were well on the way towards drying up. Even if the species concerned have eggs which are resistant to desiccation, the duration of the nymphal life of dragonflies and damselflies is such that the pools concerned must almost always disappear before the nymphs can attain maturity. Possibly certain of the nymphs themselves can survive for a time in the deeper layers of damp mud following the drying up of transient pools.

Water beetles were very much rarer than in permanent ponds, 46 per cent. of which contained them, being collected from only six (12 per cent.) of the transient pools. Only one species was present in each of the pools concerned, in sharp contrast to the complexity of the coleopterous fauna of many of the permanent ponds. The habitat is hardly a suitable one for the completion of the life history of these insects, for the same reason that applies in the case of the Odonata. While both adults and larvae were of common occurrence in permanent ponds, larvae were only found to be present in two transient pools (coll. nos. 271, 320). The adults, being winged, can of course move freely to new habitats—as can the hemipterans occurring in these pools—when the water soaks and evaporates away.

The figures for the occurrence of Entomostraca are comparable as regards category 1 (21 per cent.) and category 3 (16 per cent.) habitats. Seven of the 11 species/records were referable to the Ostracoda and two to cladocerans of the genus *Moina*. These animals, having latent eggs and being able to encyst in the adult state, are well fitted to survive periods of desiccation (Carpenter, 1928).

Molluscs were only recorded from 6 per cent. of the pools as compared with 24 per cent. of the permanent ponds studied. All the collection records are from Funasuti and apply to but one species, *Melania magna*, which was abundant in all three transient pools seen at the atoll. As these pools had only recently been

replenished by rain, and some of the snails were present in the sandy mud an inch or more below the bottom, it is considered that the species has the ability to tide over periods during which the pools dry up altogether. According to Cawston (1929) many freshwater molluscs are able to survive for long periods in moist surface soil, some of them forming a membranous epipharynx well within the shell and being able to withstand complete desiccation for limited periods. Mozley (1928) noted that in Canada certain species of *Limnaea* and *Planorbis* appear in temporary pools soon after their springtime formation, despite the fact that these pools are frozen during the winter and dry up for two months during the summer.

Amphibia were infrequently encountered in both ponds and transient pools, being most plentiful in ponded streams. Recently hatched tadpoles were found in one category 3 habitat (coll. no. 343, Queensland), the other two records concerning young adults of *Bufo marinus* (coll. no. 198, Guadalcanal) and *Hyla thalassensis* (coll. no. 213, Guadalcanal) which must have passed through the tadpole stage elsewhere.

As regards the Malacostraca, which were present in only two transient pools, the occurrence of young examples of *Caridina* sp. (Decapoda) in recently filled road rut on Guadalcanal (coll. no. 195) was surprising. As already noted, *Orchesia anomala*, an amphipod collected from this habitat at Funafuti (coll. no. 661), is more usually found in damp leaf mould than in free water.

The Plecoptera were recorded once only, the nymphs of the Pacific genera encountered being characteristically found in permanent ponds and flowing and ponded streams. Late larval stages of *Cloeon* sp. were present in the same pool in Queensland from which tadpoles were collected (coll. no. 343). This pool was located in a road rut recently filled by rain, and although it had every appearance of being purely transitory there is a possibility that it might have received a certain amount of seepage water and thus have been properly referable to category 1. In a survey of this nature, where repeated observations of each habitat cannot be made over an extended period, difficulty is always to be expected in assigning such borderline cases to the correct category.

As the "winter eggs" of rotifers are well known to be resistant to desiccation, and as no less than three species of *Brachionus* and one of *Habrotrocha* were present in numbers in one pool of an undoubtedly transient nature (coll. no. 30), it is considered likely that these animals would have been found to be present in more such pools had special methods for their collection been employed. Levander (1900) considered bdelloid rotifers especially characteristic of ephemeral rainwater puddles in the St. Åren Islands, Finland.

The only other animal recorded from transient pools were small oligochaetes, which were present in two stations (coll. nos. 172, Upolu, and 311, Funafuti). In the former station the mud and dead leaves over the whole of the bottom of the pool were quite covered by a wriggling mass of small worms of the genus *Aulophorus*. Representatives of this genus are resistant to desiccation, Buxton and Breland (1952) having reared them by flooding samples of dry material from tree holes, and the occurrence of a very large number of examples—as in the case of larval chironomids in collecting station 17<sup>1</sup>—is evidence of the recent origin of the pool in question. Scott (1910) noted that the first animals to make their appearance in a newly formed pond multiply rapidly in the absence of competition and soon dominate the pond and give it its particular character.

Protozoa (65 per cent occurrence) and microscopic algae (31 per cent occurrence) were much less evident than in permanent ponds. Organisms present in the gut of mosquito larvae from this habitat included phytoflagellates and diatoms, one or both of which were noted in larval gut contents from 40 per cent. of the pools from which mosquitoes were collected. Only fungal spores—particularly yeasts—and pollen grains were found in the case of larvae from a further 50 per cent. of these pools, while the gut contents of larvae from the remaining 10

per cent. were composed entirely of finely divided material of uncertain origin and angular inorganic particles. These facts are in accord with Tiffany's (1951) observation that Algae and Protozoa are represented by few species in rainy-weather puddles.

The actual number of individual micro-organisms present may be great, as Tiffany (1951) also observed. Thus *Phacus* and *Trachelomonas* were sometimes very plentiful in transient pools some days old (e.g., coll. nos. 30, Espiritu Santo; 172, Upolu), although neither they nor any other protozoans were ever found in newly formed rain pools. Phytoflagellates (*Phacus* and *Euglena*) were the only chlorophyll-bearing organisms present in an American temporary puddle studied by Coggeshall (1926), who found only a few examples of *Phacus* together with quantities of silica particles and clay in the gut of mosquito larvae from this habitat, while Buxton and Hopkins (1927) found a species of the same genus to be the only recognizable organism in the intestinal contents of larval *Aedes vexans nocturnus* from a Samoan puddle. The prevalence of these protozoans in transient pools may be ascribable to organic pollution and also to the low degree of alkalinity characteristic of such pools, particularly in the earlier stages of their history. Rainwater tends to be slightly acid because of the absorption of carbon dioxide by falling rain drops, and the pluvial and postpluvial stages in the history of a pool are characterized by a hydrogen ion content of pH 7 or of a rather lower value than this (Oliveira et al., 1951). This initial pH value is soon modified by the operation of a complexity of factors. Later values are influenced by the reaction of the underlying formation, by the presence of organic pollution (which forces an increase in acidity by increasing the carbon dioxide content of the water) and by the presence of vegetation. The latter factor is of particular importance, for the presence of quantities of filamentous algae or of aquatic phanerogams brings about a peak of oxygen concentration consequent upon photosynthetic activity at the height of the day. Maximum pH values are attained at this time, alkalinity becoming less marked towards and during the night when the respiration of plants and animals raises the carbon dioxide level of the water (Nicol, 1935). Nicol also noted that the hydrogen ion content of pools which, like transient ones, contain very little plant life, shows little if any diurnal variation. A relatively stable hydrogen ion content near neutrality, without the daily increase in the direction of alkalinity characteristic of water bodies having abundant vegetation, thus renders transient pools generally more suitable than permanent ones for phytoflagellates; the optimum growth of these organisms taking place under distinctly acid or at all events only slightly alkaline conditions (Kudo, 1946; Rao, 1953).

The nature of the present studies did not allow of repeated observations of the pH value for individual water bodies. However, whenever a transient pool and a permanent pond came under notice overlying the same formation and at the same time, the pH value of the former was always lower than that of the latter. Relevant collection data are as follows, these records being the only ones where a transient pool and a permanent pond were located side by side and could thus be studied simultaneously:—

Coll. no.	Category 3	Coll. no.	Category 1
200	pH 7.4	199	pH 9.5
284	pH 7.2	285	pH 7.4
301	pH 6.2	302	pH 6.8
304	pH 7.2	57 <sup>1</sup>	pH 8.0
311	pH 7.6	312	pH 8.2
58 <sup>1</sup>	pH 7.2	59 <sup>1</sup>	pH 7.4

Diatoms being more prevalent in waters of pronounced alkalinity and acidic conditions favouring the development of the Euglenidae (Rao, 1953), it would appear from the evidence presented that more detailed studies along these lines would

provide a background for the understanding of the reasons underlying the differences in the composition of the algal and protozoan populations of permanent ponds and transient pools.

It is suggested that the initial paucity of algal and protozoan mosquito larval foods in transient pools is amply compensated for by a favourable circumstance peculiar to such pools. It was repeatedly noticed that bacteria were unusually plentiful in this habitat. Whenever a transient pool dries up, those animals which are unable to move away elsewhere—as are adult Hemiptera and Coleoptera—or to encyst or otherwise prepare to withstand desiccation, must perish. The larger animals involved, for example most mosquito larvae, are attacked by non-aquatic predators as soon as they become stranded (Stehr and Branson, 1938). Ants are probably responsible for the greater part of this sort of predation in the Pacific islands. At the same time, as has been pointed out by Muirhead-Thomson (1951), drying kills most of the bacteria present so that "When such a pool is flooded with rain water there is so much dead organic—bacterial—matter available suddenly that there is a sharp increase in bacterial numbers to a much higher peak than before." Several authors, some of them referred to by Hinman (1930), have noted that the larvae of various mosquitoes—particularly the newly hatched "pin-head" stages—feed on bacteria, Duncan (1926) demonstrating that the gut contents and faeces of certain species include a bactericidal principle. Buddington (1911) found that all the necessary accessory growth factors for complete larval development are provided by *Bacillus subtilis* and *Saccharomyces cervisiae*, and reported that *Aedes aegypti* and *Culex pipiens* both develop to maturity in pure cultures of these micro-organisms. Both the dead organic material itself and the bacterial flora associated with it are thus available from the earliest stage as a source of nutriment for mosquito larvae developing in transient pools.

Nineteen species of inosquitoes were collected from transient pools.—

TABLE XXIII

SPECIES	NUMBER OF TIMES COLLECTED			Total
	Rare	Common	Abundant	
<i>C. annulirostris</i>	4	4	10	18
<i>An. farauti</i>	3	6	5	14
<i>C. pullus</i>	3	2	3	8
<i>A. vexans nocturnus</i>	1	2	4	7
<i>U. ciuinskii</i>	2	1	3	6
<i>A. lineatus</i>	2	3	1	6
<i>An. punctulatus</i>	2	2	—	4
<i>C. halifaxi</i>	2	2	—	4
<i>An. annulipes</i>	1	2	—	3
<i>U. solomonis</i>	2	—	1	3
<i>A. s. scutellaris</i>	1	1	—	2
<i>C. pipiens fatigans</i>	—	—	2	2
<i>B. hollandi</i>	—	1	—	1
<i>T. melanaceensis</i>	1	—	—	1
<i>A. alboannulatus</i>	—	—	1	1
<i>A. alboscutellatus</i>	1	—	—	1
<i>C. squamosus</i>	1	—	—	1
<i>C. sitiens</i>	1	—	—	1
<i>C. papuensis</i>	—	—	1	1
Totals	27	26	31	84

Both the dominant species in transient pools, *Culex annulirostris* and *Anopheles farauti*, have a wide range of larval habitats. The former species was recorded from water bodies referable to this category in Queensland, the Solomons (Guadalcanal and Sikaiana), Art, the New Hebrides (Espirito Santo, Aore), Fiji, Samoa and Tarawa. The next four species in order of precedence in Table XXIII exhibited a preference for transient pools over other habitats. Sixty-seven per cent. of the total collections of *Culex pullus*, 47 per cent. of those of *Aedes vexans nocturnus*, 67 per cent. of those of *Aedes lineatus* and 67 per cent. of those of *Uranotaenia ciuinskii*

are included here. The first three of these are primarily associated with puddles in New Guinea (Bick, 1951), but *Culex civiniskii* was stated to be a jungle stream breeder by Belkin (1953). The common occurrence of this mosquito in transient pools was possible due to the invasion of the habitat from more customary dry-season breeding places following prolonged and unseasonal rain. Although *Culex halifaxi* only figured in four of the collections, being found equally commonly in large simple containers and less frequently in permanent ponds and ponded streams, the results of more intensive local sampling in Guadalcanal (Belkin, 1915), New Britain (Laird, 1946) and New Guinea (Bick, 1951) have indicated its preference for transient pools over other larval habitats. It is favoured in these both by an abundance of mosquito larval prey and by the general scarcity of larger predators. *Culex pipiens fatigans*, best known as a "domestic" mosquito breeding in simple containers, invades this and other kinds of surface water habitats quite readily, particularly where there is a high level of animal pollution as in coll. no. 172. *Anopheles punctulatus*- which was pre-eminently a transient pool breeder under wartime conditions in the Solomons (Belkin et al., 1945), New Britain (Laird, 1916a) and New Guinea (Bick, 1951). *An. annulipes* and *Bironella hollandi* all have a wide range of breeding places and were found more commonly elsewhere. *Culex squamosus*, which is typically associated with green algal masses, had presumably invaded the collecting station concerned from a small stream nearby, while *Aedes s. scutellaris* and *Tripteroides melanesiensis* are primarily container breeders. The small forest pools in which these last two species were found on Futuna afforded very similar physical and biological conditions to those prevailing in closely adjacent tree holes containing larvae of these insects. *Culex siliens* is a brackish water mosquito, and its occurrence in a transient forest pool on Futuna (coll. no. 85) is of particular interest in that the collecting station was at an altitude of more than 30 metres above sea level and separated from the nearest sea cliff by more than 100 metres of heavily wooded country. A further anomalous record, that of *T. melanesiensis* from brackish water in a beached canoe, was made on this small island. These records may perhaps be indicative of a tendency for mosquitoes which normally exhibit restricted habitat preferences to utilize additional and underpopulated breeding places under conditions of isolation. The remaining four species, *Uranotaenia solomonis*, *Aedes alboannulatus*, *Aedes alboscutellatus* and *Culex papuensis* were not collected from any other habitats.

Two or more species of mosquitoes were frequently recorded from individual transient pools, as many as six being present in one such pool measuring only one metre in length, 0.5m. in breadth and 5cm. in depth (coll. no. 344, Queensland). Such associations were naturally most apparent in localities having relatively complex mosquito faunas. Just under half of all the transient pool collections were made in Guadalcanal where only six (29 per cent.) of the 21 samples included but a single species, seven (33 per cent.) having two species, six (29 per cent.) having three species and two (9 per cent.) having four species.

Larvae were rather more frequently noted as abundant or common in transient pools than in category 1 habitats, 57 (68 per cent.) of the 81 species/collections from the former being defined as such as compared with 56 (57 per cent.) of the 99 species/collections from the latter. The trend is more evident in the case of *Culex annulirostris* than in that of *Anopheles farauti*.

	<i>Culex annulirostris</i>		<i>Anopheles farauti</i>	
Habitat category	rare	common or abundant	rare	common or abundant
1	11 per cent.	56 per cent.	29 per cent.	71 per cent.
3	22 "	78 "	21 "	79 "

The differences between these two sets of figures draw attention to the fact that many of the predators characteristic of permanent ponds, such as notonectids,

the larger dytiscids and dragonfly nymphs, are subsurface feeders which more readily attack culicine larvae than anophelines (Laird, 1917). Culicines thus profit more than do anophelines from the lower degree of predation in transient pools, for surface-hunting hemipterans are common to both these and permanent ponds as are certain other surface-feeding natural enemies such as *Lutzia*, whereas subsurface predators, to the attacks of which *Culex* larvae are susceptible, are relatively rare in transient pools. Adult flies of predaceous habits, such as *Ochthera brevirostris* McJere (Ephydriidae) which preys on anopheline and chironomid larvae in isolated shallow pools in Guadalcanal, are easily avoided by culicines which escape by "sounding" (Travis, 1947). Eleven transient pools lacked any macrofauna other than mosquito larvae and contained no predaceous culicines. In these, larvae were more plentiful than in the transient pool samples as a whole, being abundant in six cases (55 per cent.) common in three (27 per cent.) and rare in only two (18 per cent.). Both the last two pools (coll. nos. 87, 304) were of very recent origin, and the few larvae present were all in the first instar and had presumably originated from eggs laid by a single mosquito. I am of the opinion that where predators do occur in these pools they take a relatively higher toll of developing mosquitoes than in permanent ponds, because of the lack of sheltering vegetation in transient pools only 10 per cent. of the latter contained emergent vegetation, 4 per cent. supported filamentous algae and none held strictly aquatic plants; the relevant figures for category 1 habitats being 57 per cent., 11 per cent. and 39 per cent. respectively.

All in all, there are obviously distinct advantages to be derived by those mosquitoes which can adapt themselves to the conditions afforded by transient pools. This was made only too apparent by the very high population levels achieved by *Anopheles punctulatus* breeding in newly-formed rain-filled pools in Melanesian battle areas during World War II, and is further evidenced by the visitations of *Aedes vexans nocturnus* which follow the commencement of the rainy season in Fiji (Paine, 1913).

To take maximum advantage of these conditions larvae must be developing in a transient pool in the earliest stages of its postpluvial phase before any predators whatsoever have put in an appearance; they must be able to withstand the high temperatures which may be attained in shallow, exposed pools of this nature and they must be able to complete their development before the water dries up. Various mosquitoes of rather catholic breeding habits such as *Culex annulirostris*, *C. pulchus*, *Anopheles farauti* and *An. punctulatus* adjust themselves readily to the second and third of these conditions. It has been shown in regard to *An. punctulatus* in New Britain, for example, that the full history from egg to adult can be completed in as short a time as six and a-half days in transient pools which are drying up rapidly, and that the developing larvae can withstand water temperatures as high as 11°C (Laird, 1946a). The most complete adaptation to transient pool conditions, however, is exhibited by certain aëdine mosquitoes. Thus *Aedes (Aedimorphus) imprimens* (Walker), although an abundant and most troublesome day-biting mosquito in and about coastal jungle in Guadalcanal, is only seldom collected in the larval state. The reason for this is that the eggs must be dried for from five to six weeks hatching taking place when the shallow jungle depressions in which they lie are flooded by rain; larval development is then completed within about three days, the larvae themselves apparently being able to withstand some desiccation (Belkin, 1915). *A. (Aedimorphus) alboscutellatus* (Theobald) has a similar life history (Belkin, 1945), its larval habitats being so short-lived that no larvae could ever be found during five months' collecting in New Britain despite the fact that adults were at all times abundant (Laird, 1946). Immature stages of this species, a few larvae of which were found in a transient pond in Queensland (coll. no. 341), are very rarely encountered and in fact were only described six years ago (Penn, 1949).

A third member of the same subgenus, *A. vexans*, is perhaps the best known of all transient pool mosquitoes. This species, which is represented in the Pacific by its subspecies *nocturnus* Theobald (Bohart and Ingram, 1916), has been most intensively investigated in the Northern Hemisphere. Its eggs appear to be deposited slightly above the existing water level of pools in process of drying. American studies indicating that they are to be found only in spots having some form of shade and on heavy rather than light soils, these conditions favouring the retention of moisture for the longest possible time (Bodman and Gannon, 1950). These authors found eggs not only in surface debris but down to a depth of two inches. Knight and Hull (1953) noted that the transient pools occupied by larvae of *A. vexans nocturnus* in the Philippines are principally located in grassy areas, while most of the oviposition sites studied by Bodman and Gannon (1950) were in wooded areas where canopy shade—occasionally operative for part of the day only—was present. It is thus significant that the shade factor was noted as positive in regard to 13 (87 per cent.) of all 15 habitats from which *A. vexans nocturnus* larvae were collected during the present studies. The available shade was afforded by canopy vegetation in all seven transient pool habitats, and by marginal plants or canopy in three of the five category 1 and the three category 4 habitats. One habitat (coll. no. 312) was obviously unshaded throughout most of the day, although eggs laid at the edge would have received a certain amount of shade from taro plants, while another (coll. no. 291) afforded developing larvae no shade whatsoever although closely cropped grass surrounded it completely.

The eggs of *A. vexans* hatch in water subject to a reduction in the amount of dissolved oxygen, such reduction being readily achieved by the activities of bacteria and yeasts (Gullin et al., 1911). It has already been shown that a high level of bacterial activity characterizes the earliest postpluvial stages of transient pools, and *A. vexans* is thus well fitted to take advantage of the period in the history of such pools during which predators are least likely to be present.

*A. vexans nocturnus* larvae can withstand high temperatures, two of my collections being from ponds at temperatures of 37°C and 38°C. It has often been claimed that the rapid growth rate of these and other transient pool larvae is linked with the fact that the temperature in such shallow pools is higher than in static ponds. However, the present results suggest that in tropical countries at least, the size and depth of a water body are often outweighed in importance as temperature regulating conditions by the influence of even quite trivial measures of shade. Thus the temperature readings for five of the six closely adjacent pairs of habitats for which the pH values have already been compared were as follows (no reading was taken in the case of coll. no. 304):—

Coll. no.	Category 3	Coll. no.	Category 1
200	32°C	199	35°C
284	30°C	285	30°C
301	27°C	302	27°C
311	32°C	312	37°C
58 <sup>1</sup>	31°C	59 <sup>1</sup>	33°C

In respect of collections 284/285 and 301/302 the shade factor was identical as regards each pair. The water temperatures were also identical, although pool no. 284 measured 0.7m by 0.3m by but 1cm to 2cm in depth, while pond no. 285 measured 1.6m by 1m by 15cm in depth; and station no. 301 was a hoofprint holding only 4cm of water while station no. 302 was a pond 20m long, 7m wide and up to 1m deep at the centre. There was no observable difference in the shade factor as regards coll. nos. 58<sup>1</sup> and 59<sup>1</sup>. Yet, although the readings were made at 1.15 p.m. and thus at the height of the day, the temperature of the transient pool, which measured 0.3m by 0.2m by 0.3cm in depth, was 2°C below



FIG. 45.—Permanent pond, Nausori, Viti Levu, Fiji.



FIG. 46.—Well, Fatoune, Uvea, Loyalty Islands.



FIG. 47.—Taro swamp, Anelgauhat, Aneityum, New Hebrides.



FIG. 48.—Transient pond, Marigal, North Queensland, Australia.



FIG. 49.—Natural swamp, Anelgauhat, Aneityum, New Hebrides.

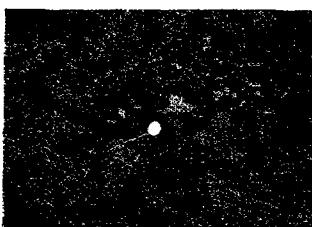


FIG. 50.—Hoofprint pools in marshy ground, Ilu, Guadalcanal, British Solomon Islands Protectorate.

that of the category 1 habitat which measured 2.7m by 1m and averaged 0.2m in depth. In the case of coll. nos. 200 and 199, a small hoofprint pool 0.5m long, 0.3m wide and 10cm deep was 3°C cooler than a seepage pond 30m long, up to 1.7m wide and averaging 8cm in depth. These readings were made towards midday, the difference between them probably being due to the fact that the surface of the water in the hoofprint pool was 8cm below ground level so that the earth walls had afforded a certain amount of shade during the morning, while the seepage pool must have been fully exposed to sunlight throughout this period. Finally, transient pool number 311 measured 0.7m by 0.3m by 2cm, but was about 3m closer to the edge of a nearby plantation than pond number 312. The surface of the former habitat was, because of this, shaded to some extent, while that of the latter one was not. The transient pool was thus 5°C cooler than the permanent pond, although this was a relatively large body of water measuring 2.7m by 0.7m by 0.3m in depth.

It would appear, then, that while there is no doubt that the temperature of exposed transient pools exhibits a greater diurnal range than that of shaded permanent ponds (Laird, 1946a), it is quite wrong to conclude that transient pools as such, because of their relative shallowness, necessarily heat up more than do water bodies which are more permanent and of greater volume. It is quite certain, for instance, that the heavily shaded jungle pools in which *Aedes alboscutellatus* and *A. impiginosus* have been found to develop so rapidly in Guadalcanal (Belkin, 1915) can never attain temperatures comparable with those reached in nearby permanent ponds in exposed places. Bates (1949) has stated that "In much of the literature on the effect of temperature on speed of larval development, little account is taken of the composition of the medium in which the larvae were maintained. Yet the nature of the culture medium may have a very considerable effect on rate of growth. . ." It may well be that the high bacterial level of transient pools is the chief factor influencing the rate of larval development in these, ensuring as it does the maximum availability of growth stimulating substances.

4. PONDED STREAMS. This habitat category embraces pools and ponds of all sizes and degrees of permanence in the beds of streams ranging in magnitude from drainage ditches to rivers. Dried-out ditches frequently contain small pools which, when trodden by stock, become like miniature marshes (e.g., coll. no. 15; Fig. 52), while small streams flowing over rock formations may, during dry spells, exhibit rock-surrounded pools closely comparable with other rock basins referable to category 6 (e.g., coll. no. 328; Fig. 55). Larger streams which cease to flow during dry seasons often form a series of deep and extensive ponds such as the one illustrated in Fig. 53 (coll. no. 370). The two extremes within this category are the short-lived pools which persist for not more than a day or so in the beds of steep, intermittent watercourses overlying porous formations (e.g., coll. no. 51; Fig. 54) and oxbows in the beds of meandering streams (e.g., coll. no. 51<sup>1</sup>; Fig. 51). Ponds of the latter sort may not be reuniting with their parent streams for long periods during which, if the hollows in which they lie are deep enough, they may be kept filled by seepage as well as rainfall. Under these conditions they simulate semi-permanent ponds of category 1.

Ponded streams may thus give rise to water bodies paralleling those of categories 1, 2, 3 and 6. Nevertheless, all collections of static water in stream beds have two things in common. The water within them, and a varying percentage of their fauna and flora, is initially derived from the streams in the beds of which they are located; and they are exposed to intermittent flushing, with subsequent replenishment and restocking by these same streams.

Fifty-five ponded streams, 10 (18 per cent.) of which did not support mosquitoes, were studied in Queensland, the Solomons, New Caledonia, the New Hebrides, Fiji, Tonga and Samoa. Their salient physical features were as follows.—

Factor	Percentage occurrence
Shade	76 per cent.
Positive temperature factor	73 " "
Availability of shelter to mosquito larvae	64 " "
Foulness	25 " "

Only 56 per cent. of the ponds were mud-bottomed, 17 per cent. having a bottom covering of dead leaves and 27 per cent. being stony bottomed. All the ponds of the latter type were located in river beds, ponded ditches being either mud-bottomed (88 per cent.) or having a bottom covering of leaves (12 per cent.). The percentage of category 4 habitats containing water noticeably polluted by animals, 25 per cent., is substantially less than that for category 1 habitats (51 per cent.). Further evidence for this is that only 15 per cent. of the former contained larvae infested with vorticellid ciliates, the figure for larvae from category 1 habitats being 33 per cent. The explanation lies in the facts that category 4 habitats are subject to intermittent flushing and are subsequently replenished with clean flowing water, and that it is often more difficult for stock to reach them than ponds not located in either ditches or stream beds. The availability of shelter to mosquito larvae (64 per cent.), although substantially less than in the case of permanent ponds (89 per cent.), is indicative of a more highly developed phanerogam and algal flora than that of transient pools, 82 per cent. of which lacked any kind of shelter whatsoever.

The totals and percentages of the faunal and floral indices for the category 4 habitats are as follows, the relevant percentages of those for category 1 habitats being repeated for comparison.—

	Faunal index	Category 4		Category 1	
		1	4 (7 per cent.)	1	4 per cent.
	1	...	4	...	4
	2	...	27 (49 " ")	49	" "
	3	...	19 (35 " ")	39	" "
	4	...	5 (9 " ")	9	" "
	Floral index	1	21 (38 " ")	10	" "
		2	31 (62 " ")	89	" "
	3	...	0	1	" "
	4	...	0		

While the faunal indices of the two habitats are thus almost exactly comparable, the static condition of category 1 ponds favours the development of more complex macrofloras.

The percentage of occurrence of the various groups of aquatic organisms proved to be as follows. . .

Animals	Diptera	...	82 per cent.
	Hemiptera	...	73 " "
	Protozoa	...	60 " "
	Coleoptera	...	47 " "
	Odonata	...	16 " "
	Pisces	...	20 " "
	Amphibia	...	20 " "
	Plecoptera	...	18 " "
	Arachnida	...	16 " "
	Mollusca	...	15 " "
	Malacostraca	...	9 " "
	Entomostraca	...	6 " "
	Rotatoria	...	4 " "
	Miscellaneous	...	4 " "

Plants	Microscopic algae	... ... ...	82	"	"
	Macroscopic algal masses	... ...	35	"	"
	Grasses, sedges, reeds	... ...	26	"	"
	Aquatic phanerogams	... ...	4	"	"

While the percentage occurrence of grasses, sedges and reeds (26 per cent.) was less than half of that in respect of permanent ponds (57 per cent.) and strictly aquatic phanerogams figured in only 4 per cent. of the collections as compared with 39 per cent. of those from category 1 habitats, only 14 per cent. of the latter supported masses of filamentous algae, these being present in 35 per cent. of the category 4 habitats. The algal masses in stream bed ponds were chiefly made up of Zygnemataceae, particularly *Spirogyra* spp., and were often plentiful enough to provide an important source of shelter to mosquito larvae (Fig. 53); on occasion (e.g., coll. no. 282, Guadalcanal) they all but choked the ponds concerned. The common occurrence of these filamentous green algae, the prolific growth of which is favoured by the general cleanliness of the water of stream ponds, largely offsets the lack of higher plants from the standpoint of larval shelter.

The percentage occurrence of the Diptera (82 per cent.) is almost exactly as in category 1 habitats (83 per cent.). Mosquito larvae were present in all of the ponds in question. Four of these contained larval Tendipedidae as well, and larval Stratiomyidae were found on two occasions.

Next in order of precedence come the Hemiptera, the percentage occurrence of which (73 per cent.) materially exceeds the figure for permanent ponds (59 per cent.). Coleoptera were present in 47 per cent. of the category 4 habitats and 46 per cent. of the permanent and semipermanent ponds. Eighteen species of water beetles were common to the two habitats, 12 others being recorded from ponded streams and 11 from category 1 habitats. Many more collections would have to be made, however, before it could be established whether any of the species found in one habitat but not in the other exhibit any special preference for the habitat concerned. This might prove to be so as regards the Gyrinidae, which are generally commoner in flowing and ponded streams than in permanent ponds. Representatives of this family were collected from 30 per cent. of the streams examined, 15 per cent. of the stream-bed ponds and 10 per cent. of the category 1 ponds. The decreasing utilization of ponded streams by Coleoptera in an eastward direction across the Pacific proceeds in direct proportion to the decreasing representation of the order. More than two species of water beetles were never recorded from the same stream bed pond from New Caledonia eastwards, but eight of the 10 such ponds studied in Queensland supported three or more species, one of them (coll. no. 371) containing no less than nine species.

Nymphs of the Odonata are rather more plentiful under the static conditions afforded by category 1 ponds, occurring in 69 per cent. of these but in only 46 per cent. of the category 4 habitats.

Fish occur more commonly in ponded streams (20 per cent.) than in category 1 ponds (10 per cent.). The initial source of the water and life-forms of the former habitat is well illustrated by this group of animals. While only a single species of fish was recorded from each of the seven permanent ponds and from eight of the stream bed ponds concerned, two others of the latter (coll. nos. 43<sup>1</sup>, 281, Guadalcanal) each held seven species and one (coll. no. 51<sup>1</sup>, Viti Levu) held four species. In these three instances most of the fishes were characteristic of lotic rather than static waters, and their isolation had only recently taken place through flooding and abatement. The presence of many such fishes in ponds of this sort may be taken as indicative of their recent formation. Most stream fish so isolated die in consequence of a decrease in the oxygenation of the water as the ponds concerned stagnate, if indeed they are allowed to survive so long by fish-eating birds to which they fall easy prey under such circumstances.

Reef herons—*Egretta sacra sacra* (Gmelin)—were fishing at both the Fijian and Solomon Island ponds upon our arrival at these collecting stations.

Amphibians too were found to be twice as plentiful in ponded streams (20 per cent.) than in permanent ponds (9 per cent.). A single species was represented in each of the six collections from the latter habitats and in 10 of the 11 collections from ponded streams, three species referable to as many genera being present in the remaining stream bed pond (coll. no. 224, Guadalcanal). Amphibians, like fishes, are favoured by the relatively clean water of streams.

The percentage occurrence of the Plectoptera, Arachnida and Malacostraca compared closely for the two habitats under consideration, while that of the Molusca and Rotatoria was rather less in the case of category 1 ponds. The Entomostreaca, which thrive in stagnant water of rather rich organic content, were collected from only 6 per cent. of the stream bed ponds but from 21 per cent. of the category 1 habitats.

As regards mosquito larval foods, 60 per cent. of the category 1 ponds were recorded as positive for Protozoa, these animals being present in 96 per cent. of the permanent and semipermanent ponds in which they flourish under conditions of stagnation. Microscopic algae were abundant in both habitats, being recorded from 82 per cent. of the ponded streams and recognized among the gut contents of mosquito larvae from 80 per cent. of the habitats containing these insects. Pollen grains and fungal spores were always present together with angular particles of inorganic matter and amorphous debris in the gut contents of larvae from the remaining habitats, as well as in those of most of the larvae noted as having ingested algae. Phytoplasmellae (*Phacus* and *Trachelomonas*) were only noted as present on three occasions, animal pollution being patent in each case.

Twenty-five species of mosquitoes were collected from category 4 habitats.—

SPECIES	NUMBER OF TIMES COLLECTED			Total
	Rare	Common	Abundant	
<i>C. annulirostris</i>	3	10	6	19
<i>An. farauti</i>	6	5	1	12
<i>An. annulipes</i>	5	3	2	10
<i>An. punctulatus</i>	2	1	3	6
<i>C. basicinctus</i>	—	2	2	4
<i>C. fraudatrix</i>	3	1	—	4
<i>An. solomonis</i>	3	—	—	3
<i>U. citrinski</i>	3	—	—	3
<i>A. vexans nocturnus</i>	1	1	—	3
<i>C. squamosus</i>	2	—	—	3
<i>C. whitmorei</i>	1	2	—	3
<i>B. hollandi</i>	1	1	—	2
<i>U. atra</i>	2	—	—	2
<i>C. bitaeniorthynchus</i>	—	—	2	2
<i>C. halifaxi</i>	1	1	—	2
<i>C. pipiens fatigans</i>	1	1	—	2
<i>An. b. bancroftii</i>	1	—	1	1
<i>T. melanosticta</i>	1	—	—	1
<i>Ay. catasticta</i>	1	—	—	1
<i>A. alternans</i>	1	—	—	1
<i>C. albiceps</i>	—	—	1	1
<i>C. cylindricus</i>	1	—	—	1
<i>C. near pseudomelanonotia</i>	—	1	—	1
<i>C. pullus</i>	—	1	—	1
<i>C. mimulus</i>	1	—	—	1
Totals	39	30	20	89

As in all the habitats thus far considered, *Culex annulirostris* and *Anopheles farauti* were the dominant species present, the former mosquito being recorded from ponded streams in all localities where these were noted with the exception

of Art, and the latter occurring in such habitats throughout its area of distribution. Ten (44 per cent.) of my 23 collections of *An. annulipes* were from category 4 habitats, which is in accord with the observation of Roberts (1948) that isolated pools left by drying rivers and creeks are a very prolific source of larvae of this mosquito in open forest country in Queensland. *An. punctulatus* was recorded from pot holes in drying stream beds in Guadalcanal by Belkin et al. (1945), although these authors found the species far more frequently in transient pools. *Culex basicinctus*, *C. squamosus*, *C. bitaeniorhynchus* and *C. albiviridis* are all primarily stream breeders the larvae of which are as already described associated with filamentous green algae, while *An. solomonis* has only been recorded from streams and their immediate vicinity (Belkin et al., 1945). The New Caledonian *Culex* near *pseudomelanocina* is likewise only known from pools in stream beds (Williams, 1943; Perry, 1950). All the remaining 15 mosquitoes listed in Table XXIV, with the exception of *Tripteroides melanesiensis*, are found in a wide variety of ground pools and their occurrence in ponded streams is regarded as adventitious. For example, one of the two stream bed ponds in which *Culex pipiens fatigans* was breeding (coll. no. 50, Art.) was in the immediate vicinity of native huts and was heavily contaminated with sewage. This fact rather than the nature of the habitat itself was the determining factor in rendering the pond concerned attractive to the mosquito. *T. melanesiensis* is characteristically a container breeder, and it has already been indicated (Laird, 1954a) that the larvae from collection number 51 were presumably flushed from some natural habitat upstream during a downpour which took place the evening before they were found.

The figures for the abundance of larvae compare closely with those for category 1 habitats.—

	rare	category 1	habitats	43 per cent.
	"	4	"	43 "
common	"	1	"	28 "
	"	4	"	33 "
abundant	"	1	"	20 "
	"	4	"	23 "

This is hardly surprising, as the factors of overall predation and vegetational shelter are much the same for both types of habitat.

The decreasing utilization of the habitat in an eastward direction from Australasia, and its absence from the atolls are indicated in the following table.—

TABLE XXV  
LARVAL ASSOCIATIONS IN PONDED STREAMS.

No. of mosquitoes present.	Queensland	Solomon Is.	New Caledonia	New Hebrides	Fiji	Tonga	Samoa	Cook Is.	Gilbert Is.	Elice Is.	Tokelau Is.	Totals.
5	1											1
4	2	1										3
3	4	2	1	1	1							8
2	3	7	3	2	1	2	1					16
1	2	5	5	2	1							17
Grand Totals	12	15	9	4	2	2	1					45

There do not seem to be any special adaptations exhibited by mosquito larvae to category 4 habitats that are not equally referable to category 1 habitats. The fact that filamentous green algae flourish particularly well in the former, however, considered in conjunction with the common occurrence of the *Culex bitaeniorhynchus* complex in flowing and ponded streams, suggests that close associa-

tions between mosquito larvae and such algae initially developed in stream bed ponds. Larvae of *Anopheles punctulatus*, *An. farauti* and *An. annulipes* all take advantage of the shelter provided by algal masses whenever this is available, although the association is facultative only. All these species are as well fitted to develop in category 1 habitats as in stream bed ponds, but their adaption to the algal shelter more readily available in the latter is a step towards life in the vegetation-choked marginal areas of flowing streams.

5. FLOWING STREAMS. Streams of every order of size are considered here. These were less commonly utilized as mosquito breeding places than any of the other surface water habitats studied, nine (30 per cent.) of the 30 dealt with lacking larvae altogether. Mosquito larvae are never found in turbulent waters (e.g., coll. nos. 32<sup>1</sup>, 34<sup>1</sup>, 36<sup>1</sup>, 77<sup>1</sup>, 80<sup>1</sup>), and rarely occur in deep, stony-bottomed backwaters supporting numerous predators and affording little plant shelter (e.g., coll. nos. 50<sup>1</sup>, 52<sup>1</sup>). As a general rule larval development takes place only in the shelter of vegetation bordering quiet streams, or among masses of filamentous green algae in more rapidly flowing ones; although the larvae of stream-breeding species are sometimes surprisingly numerous among midstream algal masses where the current is deflected to some extent by boulders (e.g., coll. no. 348; Fig. 56).

A majority (60 per cent.) of the streams encountered were stony-bottomed, only 34 per cent. having a mud bottom. Other physical characteristics may be summarized as follows.—

	Percentage occurrence
Shade	73 per cent.
Availability of shelter to mosquito larvae	69 "
Positive temperature factor	68 "
Foulness	13 "

While the first three figures are closely comparable with the relevant ones for ponded streams, that for foulness is again sharply reduced.

The faunal and floral indices, and the percentage occurrence of the various organisms concerned, are as follows.—

Faunal index	1	...	...	4	(14 per cent.)
	2	...	...	14	(50 " " )
	3	...	...	8	(29 " " )
	4	...	...	2	(7 " " )
Floral index	1	...	...	9	(31 " " )
	2	...	...	20	(69 " " )
	3	...	...	0	
	4	...	...	0	
Animals	Diptera	...	...	...	77 per cent.
	Hemiptera	...	...	...	53 " "
	Protozoa	...	...	...	47 " "
	Colcoptera	...	...	...	13 " "
	Odonata	...	...	...	33 " "
	Mollusca	...	...	...	20 " "
	Plectoptera	...	...	...	17 " "
	Pisces	...	...	...	17 " "
	Malacostraca	...	...	...	13 " "
	Amphibia	...	...	...	10 " "
	Arachnida	...	...	...	7 " "
	Rotatoria	...	...	...	7 " "
	Miscellaneous	...	...	...	27 " "
Plants	Microscopic algae	...	...	73 " "	
	Macroscopic algal masses	...	...	47 " "	

Grasses, sedges, reeds	... ..	13	"
Aquatic phanerogams	.. ..	3	"

While only 13 per cent. of the streams had emergent vegetation, which was present in 26 per cent. of the stream bed ponds studied, the consequent comparative lack of larval shelter was offset by a better development of filamentous green algae. The clean water of flowing streams affords optimum conditions for the growth of *Spirogyra* and other members of the Zygnemataceae, and the frequent presence of masses of these algae raised the figure for availability of larval shelter to 69 per cent. as compared with 64 per cent. in the case of ponded streams.

The Diptera again dominated over the other animal groups, 70 per cent. of the collections including mosquito larvae and larval Tipulidae and Tendipedidae occurring as well although relatively rarely.

Although the Hemiptera were noticeably less well represented than in category 4 habitats (53 per cent.: 73 per cent.) members of several families nevertheless occurred quite commonly. The Veliidae and other stridling bugs were often found running about over the surface of quiet backwaters, while *Enithares* and *Micronecta* were occasionally present in still pools. The best adaptation to stream conditions was exhibited by a species of *Rhagovelia* from Guadalcanal hill country rivers. This insect, which has very hairy tarsi and inflated femora, is well equipped for life even on the turbulent waters of rapids.

The percentage of streams from which Coleoptera were collected (43 per cent.) was close to that for ponded streams (47 per cent.). Of the 14 water beetles from this habitat determined as to species, 12 were also found in ponded streams and nine in permanent ponds. Eighteen species records were derived from six Queensland streams, but only nine from the seven such collections from Pacific islands.

A lower proportion of streams than of any other habitats thus far discussed were found to support Odonata. Amphibians were appreciably less common than in ponded streams (10 per cent.: 20 per cent.), while a few miscellaneous records of primarily stream-dwelling insects (larval Plecoptera and Trichoptera and the Fijian aquatic cricket *Hydropedeticus*) were made only from flowing water. The percentage occurrence of the remaining groups was much the same for both category 4 and 5 habitats.

Protozoans and microscopic algae were both rather less plentiful than in ponded streams, but with one exception diatoms formed the major part of the gut contents of mosquito larvae collected from this habitat. The single collection of *Culex pipiens fatigans* was from a Fijian stream (coll. no. 1) carrying a considerable quantity of sewage. The larvae, which were very abundant in the quieter backwaters, were heavily infested with the sewage protozoan *Vorticella microstoma* which was also plentiful on submerged pieces of timber; and their gut contents were composed almost entirely of bacteria.

Eleven species of mosquitoes were recorded from flowing streams.—

TABLE XXVI

SPECIES	NUMBER OF TIMES COLLECTED			Total
	Rare	Common	Abundant	
<i>An. punctulatus</i>	.. ..	3	—	4
<i>C. basicinetus</i>	.. ..	1	1	4
<i>C. squamosus</i>	.. ..	—	3	4
<i>An. annulipes</i>	.. ..	—	2	3
<i>An. fassatti</i>	.. ..	2	1	3
<i>C. annulirostris</i>	.. ..	3	—	3
<i>C. albimaculata</i>	.. ..	1	—	2
<i>An. b. bancroftii</i>	.. ..	1	—	1
<i>B. hollandi</i>	.. ..	1	—	1
<i>C. fraudatrix</i>	.. ..	1	—	1
<i>C. pipiens fatigans</i>	.. ..	—	1	1
Grand Totals	.. ..	11	10	27

The common occurrence of *Anopheles punctulatus* and *A. annulipes* in ponded streams has already been pointed out. Most flowing stream collections of these species were from among floatage or vegetation in the relatively still water of stream backwaters or margins (coll. no. 348, fig. 56). The ubiquitous *Culex annulirostris* and *A. farauti* are less in evidence here than in other surface water habitats, and are restricted to quiet water affording vegetational or other shelter.

Optimum conditions for the species of the *bitaeniorhynchus* complex prevail in the quieter parts of streams supporting heavy growths of filamentous algae, and one of these species, *C. basicinctus*, exhibits an adaption which fits it particularly well for this mode of existence. The apico-dorsal hairs of the siphon are modified to stout, recurved spines, by means of which the larva is able to remain anchored in algal masses even when these are in the body of the stream itself. Larvae of *C. basicinctus* may even be collected from "beards" of *Spirogyra* streaming off in the current from the down-river surfaces of boulders (coll. no. 63, New Caledonia). Numerous other Pacific mosquitoes, including the remaining ones listed in Table XXVI, breed from time to time in stream backwaters, but are primarily fitted for life in static waters.

The overall influence of predation and vegetational shelter is much as in category 4 habitats, the relevant figures for larval abundance being.—

	rare	category	4 habitats	43 per cent.
common	"	5	"	41 "
	"	4	"	33 "
	"	5	"	37 "
abundant	"	4	"	23 "
	"	5	"	22 "

My association records emphasize the fact that streams are less frequently utilized as mosquito larval habitats than category 4 ponds. Thus a single species was represented in 16 (76 per cent.) of the 21 stream collections, whereas only 17 (38 per cent.) of the 45 collections from ponded streams included but one species; and only one station (coll. no. 369, Queensland) yielded as many as three different mosquitoes.

6. LARGE SIMPLE CONTAINERS. A total of 72 of these were studied, 10 (14 per cent.) of them lacking mosquito larvae. Twenty-one of the habitats were of natural origin, 10 of these being rock-surrounded pools and rock crevices, which have many affinities with permanent ponds, and 11 being pot holes in rock platforms and large holes in boulders, the biology of which is closely comparable with that of large artificial containers. The remaining 51 breeding places were man-made. The most numerous group of these were large metal containers, 34 of which were encountered, ranging in size from domestic water tanks and abandoned whaling try pots through 44 gallon drums—legacies of World War II widely distributed throughout the Pacific and now used primarily as water butts (Fig. 57)—to kerosene tins. Collections were also made from eight rubber tyres, from five wooden dug-out containers and from four troughs and tanks of concrete.

As mentioned earlier the borderline between this category and the next defies rigid definition. However, as a generalization it may be stated that the water in category 6 habitats may be measured in litres, while that in category 7 habitats rarely exceeds two or three hundred cubic centimetres except in the case of the largest tree holes.

The salient physical features of the habitat are summarized below.—

Factor	Percentage occurrence
Shade	80 per cent.
Positive temperature factor	67 "
Foulness	31 "
Availability of shelter to mosquito larvae	11 "

The nature of the bottom is the only criterion which can separate rock-surrounded pools and rock crevices and pot holes from category 1 habitats. All habitats referable to category 6 are surrounded by non-porous material, whether rock, metal, wood or such artificial substances as rubber or concrete. Fifty-four per cent. of the large containers studied were bare of any bottom covering, 38 per cent. held dead leaves, three per cent. contained stones and in the remaining five per cent. a thin layer of mud was present. Emergent plants and filamentous algae were rarely present, and then only in the larger rock pools. This fact, together with the trend towards a total lack of any bottom covering, renders category 6 habitats notably deficient as regards the availability of shelter to mosquito larvae.

The faunal and floral indices of large simple containers are low.—

Faunal index	1	.....	38	(53 per cent.)
	2	.....	32	(44 " "
	3	.....	2	( 3 " "
	4	.....	0	)
Floral index	1	.....	66	(92 " "
	2	.....	6	( 8 " "
	3	.....	0	)
	4	.....	0	)

Individual groups of animals and plants occurred as follows.—

Animals	Diptera	.....	90	per cent.
	Protozoa	.....	42	" "
	Hemiptera	.....	14	" "
	Odonata	.....	13	" "
	Coleoptera	.....	10	" "
	Arachnida	.....	6	" "
	Entomostriata	.....	4	" "
	Malacostraca	.....	3	" "
	Mollusca	.....	3	" "
	Rotatoria	.....	3	" "
	Pisces	.....	1	" "
	Miscellaneous	.....	3	" "
Plants	Microscopic algae	.....	22	" "
	Grasses, sedges, reeds	.....	4	" "
	Macroscopic accumulations of filamentous algae	.....	3	" "

Mosquito larvae were the dominant organisms of the habitat throughout the area of the survey, being present in 62 of the 65 large containers which held Diptera. Endopidae were present in the remaining three containers, and in 10 of the others as well. This family, with a percentage of occurrence of 18 per cent., thus took second place to the Culicidae in the macrofaunal list. The only other Diptera recorded were larval Cyclorrhapha (twice), Syrphidae (once) and Heleidae (once).

The insect orders which include the main natural enemies of mosquito larvae were of only limited occurrence. Water striders (Gerridae, Veliidae, Mesovelidae) were often present on the surface film of rock pools, individuals of *Microvelia* sometimes being very abundant (p. 76). The Hemiptera only rarely invade artificial containers, notonectids occasionally being found in metal drums (*Anisops* sp., coll. no. 41!) and microveliids occurring in these from time to time. Dragonfly nymphs (Odonata: Anisoptera) are sometimes present in rock pools, and were recorded from a concrete trough on Tutuba (coll. no. 29), while damselfly nymphs (Odonata: Zygoptera) were collected from artificial containers on four occasions. Nymphs of an unidentified damselfly were abundant in wooden water containers

on *Bellona* (coll. nos. 231, 40<sup>1</sup>) as well as in a pool in a coral boulder (coll. no. 232), in the complete absence of surface water habitats. What appeared to be the same species was also collected from a 44 gallon drum at Lavanggu, Rennell (coll. no. 247), while larvae of *Ischnura torresiana* were found in a try pot at Aneityum (coll. no. 2) as well as in habitats referable to categories 1 and 9.

Although water beetles were only collected from seven (10 per cent.) of the large containers examined, the records yield data of some interest. With the exception of the medium-sized *Platynectes insularis*, a species taken elsewhere in stream bed ponds and which was present in a large rock crevice above the flood level of the Nevala River, Espiritu Santo (coll. no. 36), all the beetles concerned were of small size. The genus *Copelatus* was represented in all six of the remaining collections. *C. cheesmanae*, which was abundant in a 14 gallon drum (coll. no. 96) and a truck tyre (coll. no. 98) at Aneityum, was also found in the marginal areas of a permanent pond and a ponded stream. *C. gentilis*, found in association with an undescribed species of *Guignotus*, in an iron pot at Sikaiana (coll. no. 45<sup>1</sup>), was taken at Aore in the shallow water of a marsh and at Tutuba at the edge of a permanent pond. A pot hole in Queensland (coll. no. 346) included *C. irregularis* in addition to two other beetles referable to *Paracymus* and *Hydrena*, the first-named species also being collected from flowing and ponded streams and a permanent pond. Finally, an undescribed species of *Copelatus* was present in water held in a large hole in a boulder in Guadalcanal (coll. no. 38<sup>1</sup>) and three species of this genus, one of them undescribed and two known elsewhere from the marginal areas of ponds, were found in a pot hole in Viti Levu (coll. no. 48<sup>1</sup>). Members of the genus *Copelatus* are often very plentiful in the shore zone of habitats referable to categories 1, 2, 4 and 5, which is in accord with the observation of Needham and Williamson (1907) that the size of water beetles is graded according to the distance of the niche they occupy from the shore, the larger species being furthest out in the water. This statement receives general support from my field observations, the largest species found, for example (*Cybister triplunctatus*, c.25mm), only being collected from relatively deep water some way out from the shore of large ponds. It would appear that small beetles which have become adapted to life in the shallow marginal areas of ponds where they do not have to compete with larger species can adjust themselves equally well to life in containers, where predaceous dytiscids such as *Copelatus* spp. are not only free from competition with larger species of their own kind but also have the advantage of an abundance of food in the form of mosquito larvae.

The next group in order of occurrence, the Arachnida, was only recorded from four large containers, all these being rock pot holes. Water spiders of the genus *Dolomedes* were present on two occasions, the other records referring to Argiopidae which had spun horizontal webs immediately above the water surface. The remaining macrofaunal records concern animals which were collected on one or two occasions only, all the specimens in question being from natural containers with the exception of a nematode found in a concrete trough and collembolans which were present on the surface film of water in a truck tyre (coll. no. 194, Espiritu Santo).

Protozoa were seldom abundant, and were recorded from only 42 per cent. of the habitats. *Phacus pleuronectes* was quite plentiful in a large rock pool in Samoa (coll. no. 29<sup>1</sup>), and the alimentary tract of larvae of *Culex annulirostris*, *C. pallidus* and *Anopheles farauti* from a 44 gallon drum (coll. no. 276, Guadalcanal) was crammed with examples of an undetermined species of *Euglena*. Dead leaves at the bottom of a rock pot hole in Viti Levu (coll. no. 48<sup>1</sup>) were covered with masses of the large (3mm) ciliate *Spirostomum ambiguum*. The milky white patches formed by the clustered protozoans measured up to 5cm in diameter when the collection was made at 10 a.m. In Australia, Wentworth (1937) noted "swarming" of a species of *Spirostomum* as a purely nocturnal phenomenon. Diatoms

were prevalent in rock pools, but only formed the major part of the gut contents of mosquito larvae on one occasion (in *Culex femeineus*, coll. no. 35, Espiritu Santo). These algae were not seen at all in artificial containers, although a 44 gallon drum in Aneityum (coll. no. 96) held large numbers of *Scenedesmus dimorphha* and *S. bijuga* (Chlorococcales) with which the gut of *Culex pipiens fatigans* larvae from this station was crammed. Most of the larvae from large containers were found to have ingested chiefly amorphous debris, possibly of organic origin, and inorganic particles. Yeasts and the spores and hyphae of other fungi were often in evidence in the gut contents, as were insect hairs and scales. In the case of larvae from drums and other metal containers the entire ingested mass was usually tinged a reddish-brown colour by rust particles.

Sixteen species of mosquitoes are recorded from category 6 habitats.—

TABLE XXVII

SPECIES	NUMBER OF TIMES COLLECTED				Total
	Rare	Common	Abundant		
<i>A. scutellaris</i>	3	5	11		19
<i>C. pipiens fatigans</i>	4	2	11		17
<i>A. polynesiensis</i>	3	4	8		15
<i>C. annulirostris</i>	2	3	3		8
<i>T. melanesiensis</i>	2	1	2		5
<i>C. fraudatrix</i>	1	2	2		5
<i>A. aegypti</i>		1	2		4
<i>A. perniciosus</i>	1	2	2		4
<i>C. halifaxi</i>		3	-		1
<i>A. albimanus</i>	1	-	2		3
<i>C. pullus</i>		2	1		3
<i>An. farauti</i>	2	-	-		2
<i>C. femeineus</i>	-	-	2		2
<i>C. albimanus</i>	-	-	1		1
<i>C. pacificus</i>	-	1	-		1
<i>C. sitiens</i>	-	-	1		1
Totals	20	26	48		94

*C. annulirostris*, although primarily a surface water breeder, readily utilizes rock holes and even the larger artificial containers as larval habitats; but it does not appear to be able to adapt itself to the restricted conditions of life in small containers. *Culex pullus* is another primarily surface water breeder which not only utilizes both natural and artificial containers referable to this category, but which, according to Bick (1951) may even be found breeding in coconut shells, tree holes and water cupped in fallen leaves. The larvae of *Anopheles farauti* and *Culex halifaxi* likewise occur from time to time in large containers, both natural and artificial, and on rare occasions have been collected from small simple containers. The first three of these species head my list of transient pool breeders, while previous studies have indicated that *C. halifaxi* exhibits a preference for transient pools over other larval habitats. *C. femeineus* was collected from stream bed pools in Espiritu Santo (its favourite habitat according to Perry, 1946) as well as from a rock crevice and a 44 gallon drum, and Buxton reported his finding larvae in a little well and tree holes containing from about a gallon to 10 gallons of water (Buxton and Hopkins, 1927).

*Culex pipiens fatigans* and *Aedes aegypti* are "domestic" species the larvae of which are very often present in large simple containers. The latter insect also utilizes small artificial containers as breeding places in the Pacific, but does not occur there in the small natural containers, such as tree holes, which seem to be its original habitat in Africa. Small artificial containers are relatively seldom utilized by *C. pipiens fatigans*, the larvae of which are sometimes found in polluted surface water habitats including transient pools.

*Aedes a. scutellaris*, *A. polynesiensis*, *A. perniciosus*, *A. albimanus*, *Tripteroides melanesiensis* and *Culex pacificus* are all primarily container breeders occurring in

large and small containers whether natural or artificial. The first-named species readily utilizes rock pools, and figured in two of our transient pool collections; Penn (1947) recorded it from 15 puddles out of a total of 219 collections from New Guinea. One collection of *T. melanesiensis* larvae was also made from a transient pool. Although *A. polynesiensis* was never found in category 3 habitats this species, like *A. s. scutellaris*, occurs from time to time in quite large rock pools and Buxton and Hopkins (1927) recorded it (*= A. variegatus* var. *pseudoscutellaris*) from open concrete drains and a crab hole in Samoa. The related *A. pseudoscutellaris* has likewise been recorded from temporary pools in soapstone drains and trenches in Fiji (Lever, 1943; 1943a). Finally, Buxton found *C. pacificus* larvae in a shallow well in addition to container habitats in Espiritu Santo (Buxton and Hopkins, 1927).

*C. fraudatrix*, which usually exhibits a preference for surface water habitats of a permanent nature, was found to utilize natural and artificial containers in the absence of surface water on Rennell and Bellona. The remaining records in the list of mosquitoes from category 6 habitats are regarded as adventitious. Thus the rock pot hole from which one of the collections (no. 303) of *C. albincrus* was made supported a prolific growth of *Spirogyra*, the presence of which rather than the nature of the habitat was presumably the determining factor in the selection of this breeding place.

The interrelationships between the mosquito faunas of transient pools and large simple containers are of some interest. Although the latter breeding places are of a more permanent nature than the former, water loss taking place by evaporation only, the biological and physical characteristics of the two types of habitat have much in common. The pH value tends to remain low in both cases, and the temperature of the water usually rises above that of the air during the day. Species primarily found in either one of these habitats have little available surface shelter and develop in the presence of relatively poor algal floras and protozoan faunas. In both cases any disadvantages in consequence of these facts are offset by a relative freedom from predation, which is reflected in the development of greater numbers of larvae than in habitats referable to categories 1 and 4 where predators abound. Thus larvae were noted as abundant or common in 68 per cent. of the 84 species/collections from transient pools and from 79 per cent. of the 94 such collections from large simple containers. It is not considered that mosquito larvae exhibit any special adaptations to life in category 6 habitats, the majority of which are made use of by species more particularly adapted for life in small containers. The facts that some of the container breeders of less restricted habitat are able to invade transient pools and that some traffic takes place in the reverse direction, indicate that large simple containers bridge the gap between surface water environments and the smaller and more specialized types of container. Ancestral culicines probably used this route in the migration from ponds toward the ultimate utilization of small and specialized container habitats, while subsequent reinvasions of surface water habitats—as, for example, by species of *Aëdes* (*Aëdimorphus*)—have been rendered possible by the same link between the two major groups of freshwater mosquito breeding places.

7. SMALL SIMPLE CONTAINERS. Of the 71 such habitats studied only six (8 per cent.) did not contain any mosquito larvae. Sixty-three of them were of natural origin, the most numerous types being tree holes (29), half coconut shells (14) and pierced coconuts (8). Seven collections were made from small crevices in boulders (Fig. 58), three from fallen palm fronds, one from a rat-gnawed cacao pod and one from a cut bamboo stem. Only eight collections were made from small artificial containers such as tin cans and corrugated roofing material.

The salient physical features of the small simple containers examined are presented below.—

Factor	Percentage occurrence
Shade	91 per cent.
Foulness	52 "
Positive temperature factor	46 "

Only 24 per cent. of these habitats were bare of any bottom covering, such containers as tree holes, half coconut shells and crevices in boulders usually containing dead leaves, these being present in 74 per cent. of the category 7 habitats. Only 38 per cent. of the category 6 habitats seen had a bottom covering of leaves, the more general occurrence of the latter in small containers being correlated with the finding of a higher percentage of these in forested areas, and occasioning increases in turbidity and foulness. Wesenberg-Lund (1920-21) drew attention to the generally high organic content of water in tree holes, pointing out that this is due to the decomposition both of plant material and of drowned arthropods and other animals swept into the holes by rainwater running down the trunks of the trees concerned. The relatively high level of vegetable decomposition in category 7 habitats is also linked with a general rise in acidity, the water in coconut husks and tree holes containing dead leaves usually being of distinctly acid reaction. That in clean tins and coconut shells, and in tree holes containing relatively pure water such as the coconut palm reservoirs of the Tokelau Islands, tends on the other hand to be of neutral reaction or somewhat alkaline. The mean pH value for all the small containers from which a reading was taken was 7.0, that for category 6 habitats being 7.2. An increase in shade is correlated with a decrease in the temperature of the water as compared to that of the air, a positive temperature factor being recorded for only 46 per cent. of the category 7 habitats as compared with 67 per cent. of the large simple containers. The water in tree holes having only a narrow aperture some distance above the water surface never receives any sunlight at all, and its midday temperature is often 2°-3°C below the prevailing air temperature. Garnham et al. (1946) reported such differences of as much as 6°C in regard to tree holes in Kenya.

The faunal and floral indices of small simple containers proved to be lower than those of any of the other habitats thus far discussed.—

Faunal index	1	53	(75 per cent.)
	2	18	(25 " "
	3	0	
	4	0	
Floral index	1	71	(100 " "
	2	0	
	3	0	
	4	0	

The plant life of these habitats was limited to fungal spores and yeasts, the latter sometimes being very abundant in coconuts pierced by land crabs or other animals and containing decomposing copra. The complete lack of diatoms was rather surprising, for Beattie and Howland (1929) listed numerous diatoms, also *Chlorella* and *Pleurocoleus*, from English tree holes, stating that the species concerned were epiphytic or soil forms which had been carried into the holes by falling leaves. Animals were recorded as follows.—

Diptera	...	97	per cent.
Protozoa	...	53	" "
Entomostraca	...	4	" "
Odonata	...	3	" "
Hemiptera	...	1	" "
Coleoptera	...	1	" "
Malacostraca	...	1	" "

Hydracarina	....	....	1 per cent.
Rotatoria	....	....	1 " "
Miscellaneous	....	....	1 " "

Most of the records of Diptera were of mosquito larvae, and four habitats from which these were absent contained representatives of other families. Maggots of cyclorrhaphid flies were recorded 11 times, notably from coconut husks in which some decomposing copra still remained, and this same source yielded undetermined Syrphidae on three occasions. Larval chironomids were present in seven small containers, *Tendipes* sp. being recorded from crevices in boulders and from an artificial container, *Polydora* sp. occurring in a tree hole and *Pontaneura* sp. being found in a cut banana stem. Psychodid larvae figured in three collections, *Psychoda* sp. being taken from pools and husks and *Telmatoscopus* sp. from a tree hole. Lastly, a species of *Dasyhelea* (Heleidae) was found breeding in two tree holes on Futuna.

The dominance of the Diptera in these habitats is in accord with findings elsewhere. Thus Wesenberg-Lund (1920-21) found mosquito larvae and numerous Tendipedidae, Heleidae and Syrphidae in tree holes in Denmark, Beattie and Howland (1929) recorded representatives of the first and last of these families, also larval Anthomyiidae, in English tree holes, and Buxton and Breland (1952) reared Tendipedidae, Holcidae, Syrphidae and Psychodidae from material taken from the bottom of dried-out tree holes in America.

Very few insects other than Diptera were recorded from category 7 habitats. Odonata were collected twice, Hemiptera once. Coleoptera once and Collembola once. These records may all be regarded as adventitious with the exception of one of a damselfly nymph (Zygoptera) from a tree hole on Bellona—this was referable to the same species already mentioned as utilizing category 6 habitats on that island. The other record for the Odonata concerns a dragonfly nymph which was taken from the same tree hole in Guadalcanal (coll. no. 33<sup>1</sup>) as the hemipteran (*Microvelia*) sp. The tree hole in question was a slit along the top of a log lying across a mountain stream only two feet above the water surface, and these insects had doubtless been stranded there when the water receded after a period of heavy rainfall. A coconut husk at Funafuti yielded numerous examples of a nitidulid beetle, *Haptoncus oculatus*, at all stages of development. This insect is not, however, a true water beetle, and was primarily associated with the decomposing copra within the husk (coll. no. 64<sup>1</sup>). Finally a collembolan of the genus *Drepanocylus* was present in numbers on the surface film of a tree hole (coll. no. 152) at Nukunono.

Both Wesenberg-Lund (1920-21) and Beattie and Howland (1929) reported larval beetles of the genus *Helodes* from tree holes. Although these were not taken in category 7 habitats in the Pacific they were recorded from leaf axils. Wesenberg-Lund also noted that collembolans are frequently swept onto the surface of tree holes by rain.

As regards the Entomostraca, two of my three records are from Nukunono, where undetermined cladocerans and a cyclopoid, also an ostracod of the genus *Cypridopsis* (collected elsewhere from a leaf axil), were present in tree holes. Another cyclopoid was abundant in a coconut shell at Tarawa. Small copepods appear to be relatively more plentiful in plant axils than in simple containers in the Pacific. The single record of the Malacostraca was from Nukunono, a grapsid crab of the genus *Sesarma* being present among dead leaves at the bottom of a tree hole (coll. no. 156). The bivalve rotifer *Habrotrocha tridens* was abundant in a tree hole (coll. no. 325) in Viti Levu, as was a water mite of the genus *Arrenurus* in a tree hole (coll. no. 88) at Futuna. Copepods and ostracods are very common in tree holes in Denmark (Wesenberg-Lund, 1920-21), as are rotifers in that country and also in England (Beattie and Howland, 1929); and Buxton and Breland (1952) reared species of *Daphnia*, *Cyclops* and other small crustaceans from samples

of material taken from the bottom of dried-out tree holes in America. While it is thought likely that a really thorough sifting of all the debris present at the bottom of many of the tree holes and other small containers seen in the Pacific might have revealed the presence of Entomostraca, rotifers and water mites in some at least of the habitats from which no representatives of these groups were recorded, it is unlikely that any heavy populations escaped notice.

Protozoans were noted in approximately half of the small containers studied, small colourless flagellates and holotrichous ciliates being the commonest representatives of the phylum. *Bodo caudatus*, *Monas* sp., *Chilomonas paramecium*, *Coleps elongatus*, *Colpidium colpoda* and *Paramecium* sp. were all identified from these habitats, as were phytoflagellates (*Phacus pleuronectes*, *Phacus* sp.), *Trachelomonas hispida* and *Euglena* sp.) and a testacean, *Difflugia* sp. Wesenberg-Lund found "countless numbers of Infusoria" in tree holes, Beattie and Howland recorded *Trachelomonas hispida*, *Euglena quartana* and two other flagellates and Buxton and Breland named *Paramecium* sp. as the most common protozoans in their material. Buxton and Hopkins (1927) noted numerous small transparent flagellates in centrifuged water from a Samoan tree hole. Bacteria were especially plentiful in small containers in which the water was fouled by decomposing vegetable matter, and fungal spores and hyphae were always abundant amongst the finely divided amorphous material which filled the alimentary tract of all larvae dissected. Phyto-flagellates were recognized as usual in the gut contents of larvae from habitats where these protozoans occurred. The food value of common but small and colourless protozoans, which would not remain recognizable once ingested, was referred to by Buxton and Hopkins (1927). Bacteria, too, probably play an important part in the nutrition of mosquito larvae developing in small containers.

Nineteen species of mosquitoes were collected from category 7 habitats.

TABLE XXVIII

SPECIES	Rare	NUMBER OF TIMES COLLECTED		Total
		Common	Abundant	
<i>A. polynesiensis</i>	—	2	21	23
<i>A. scutellaris</i>	6	4	5	15
<i>T. melanesiensis</i>	2	—	9	11
<i>A. papuensis</i>	—	1	2	3
<i>A. pseudoscutellaris</i>	2	1	—	3
<i>U. quadrangularis</i>	—	—	2	2
<i>T. purpurea</i>	—	1	1	2
<i>A. albibrasis</i>	—	1	1	2
<i>A. albivittatus</i>	—	—	2	2
<i>A. pernotatus</i>	—	1	1	2
<i>C. pipiens f. gallicus</i>	—	1	1	2
<i>An. farauti</i>	1	—	—	1
<i>A. samoanus</i>	1	—	—	1
<i>A. morsallensis</i>	—	—	1	1
<i>A. quasiscutellaris</i>	—	—	1	1
<i>A. tongueae</i>	—	—	1	1
<i>C. fraudatrix</i>	—	—	1	1
<i>C. halifaxi</i>	1	—	—	1
<i>C. pacificus</i>	1	—	—	1
Total	14	12	19	75

Only two primarily surface water breeders, *Anopheles farauti* and *Culex fraudatrix*, were recorded from small simple containers. The former species was taken from a half coconut shell at Aote (coll. no. 13), Dwyer (1945, New Hebrides), Belkin et al (1945, New Hebrides and Solomons) and Horsfall and Porter (1946, New Guinea); all failed to find *An. farauti* larvae in coconuts, although Dwyer mentioned that they had been reported elsewhere from this habitat and himself occasionally found them in tin cans. Laird (1946, New Britain) collected larvae

from tins and once from a tree hole, and on one previous occasion (1915, unpublished) found larvae and pupae in a halved coconut shell. The latter collection was made on April 25, 1915, in a coconut plantation near the Renée River, Espiritu Santo, just across Segond Channel from Aore. Field data indicate that both of my records of *An. farauti* from coconut husks might be misleading, in that these containers were located in marshy areas from which their larvae might have been derived by stranding following flooding during heavy rain. However, the records from small cans and from a tree hole indicate that *An. farauti* is plastic enough in its selection of larval habitats to utilize category 7 habitats on occasion, notably during periods when it is unusually abundant. The single record concerning *Culex fradatris* larvae is from a tree hole at Bellona (coll. no. 237). As already noted, this mosquito has adapted itself to life in containers on that island, in the absence of surface water breeding places.

Members of the *scutellaris* complex of *Aedes* are the most ubiquitous small container breeders in the South Pacific, while *Tripteroides melanostensis* is very common in category 7 habitats in the New Hebrides. The latter species is rather less frequently noticed in large simple containers, and should probably be regarded as primarily adapted to the conditions afforded by tree holes and coconuts. Most of the other species listed in Table XXVIII are of local significance only. One of them, *Aedes samoanus*, is primarily adapted to life in leaf axils (category 8), and its occurrence in a tree hole collection (no. 169) is regarded as unusual. *Uranotaenia quadrimaculata* readily invades leaf axils on Guadalcanal, but is most frequently met with in small simple containers (Belkin, 1953). Buxton and Hopkins (1927) never found larvae of the *scutellaris* complex in leaf axils, and my only such record concerns a single collection of *A. tongae* from a *Pandanus* axil at Sikiana (coll. no. 287). *A. pseudoscutellaris*, however, is known to utilize large *Alocasia* axils as larval habitats in Fiji (Paine, 1913).

No mosquito predators utilize category 7 habitats in the South Pacific, with the exception of *Culex halifaxi* in the Solomons and the introduced *Toxorhynchites splendens* in Fiji. Neither are there any records of parasitism east of the Solomons. The tendency for larvae to be present in large numbers is as pronounced as in the case of category 6 habitats, larvae from 81 per cent. of the 75 species/collections from small simple containers being listed as common or abundant. Larval associations were found to be less evident in category 7 than in category 6 habitats.—

No. of species present	Category 6			Category 7		
	No. of collections	Percentage of total		No. of collections	Percentage of total	
4	2	3 per cent.		-	—	
3	7	11 "		—	—	
2	12	19 "	"	10	15 per cent.	
1	41	66 "	"	55	85 "	"

The explanation of this probably lies in the more intensive interspecific competition arising from the availability of only small volumes of water in the habitats under consideration.

Hopkins (1952) pointed out that the antennae, head chaetotaxy, siphon and ventral brush of small container larvae are all considerably reduced, considering these modifications to be adaptations to the small amount of swimming space available. He also drew attention to the facts that the anal papillae of such larvae are typically large and sausage shaped, while there is a tendency for numerous large tufts of setae to be developed on the thorax and abdomen. These modifications occur in varying degree among the species listed in Table XXVII, being absent in the primarily surface water breeders which only rarely utilize small simple containers and most pronounced in the primarily leaf axil breeders. Wigglesworth (1938) demonstrated that the chief function of the anal papillae of mosquito larvae is



FIG. 51. Oxbow of Nambikwest Creek, near Sova  
Viti Levu, Fiji.



FIG. 52. Headwater pond in ponded drainage ditch  
Ari Vata, near Noumea, New Caledonia.



FIG. 53. Still backwater of stream near Townsville,  
North Queensland, Australia.



FIG. 54. Transient pool on the mud-bottomed bed  
of an intermittent watercourse, photographed a  
few hours after it had been replenished by a  
downpour. Uala, Ati Island, Belep Islands.



FIG. 55. Dry-season rock-surrounded pool in the  
bed of a creek near Meewana, North Queensland, Australia.

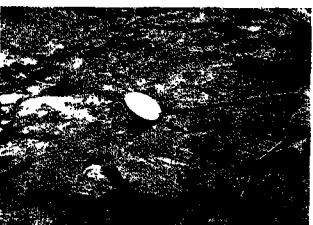


FIG. 56. Flowing stream near Cairns, North  
Queensland, Australia.

the absorption of chlorides, and that the size of these structures is in inverse proportion to the amount of chlorides available. Substantial variation of the volume of the papillae can be brought about simply by altering the chloride concentration of the environment, as Wiggleworth proved by his experiments. Recent work has indicated that the hairiness of certain smaller container larvae is also directly referable to variable environmental conditions, Rosen and Rozeboom (1951) having traced the development of long, thick setae apparent in some batches of larvae of *Aedes polynesiensis* and *A. pseudoscutellaris* (e.g., coll. no. 317) to the influence of an as-yet unisolated factor associated with the debris in the habitat. These authors stated that the factor concerned ". . . apparently occurs most commonly in tree holes, though not in all tree holes, or a majority of tree holes, or even in the same tree hole at all times."

Small volumes of water in containers are apt to dry up altogether from time to time, and the eggs of mosquitoes well adapted to category 7 habitats, like those of transient pool breeders, exhibit marked resistance to desiccation. Buxton and Hopkins (1927), working with *Aedes polynesiensis* (= *A. variegatus*) and *A. aegypti* (= *A. argenteus*) in Samoa, suggested that, as rainwater is a few degrees cooler than the air, sudden cooling may provide the necessary hatching stimulus. They also drew attention to the possible influence of micro-organisms in this connection, and the results of more recent work (Gjullin et al., 1951) make it appear that hatching is chiefly governed by a reduction in the amount of dissolved oxygen in the water consequent upon intense bacterial activity which takes place immediately after small containers holding dried organic material are replenished by rain, for the same reasons applicable in the case of transient pools.

8. SPECIALIZED CONTAINERS. Thiemeann (1934) subdivided epiphytic waters into two main groups, those at least in part of plant origin and those derived from rainwater. He further subdivided the first of these groups on the basis of the presence (e.g., *Nepenthes*) or absence (e.g., Zingiberaceae) of digestive secretions, and the second accordingly as to whether the water is stored in chlorophyll bearing parts of plants (leaf bases) or in non-chlorophyll bearing parts such as bamboo tops and tree holes.

While it is difficult to give a hard and fast ruling on the borderline between category 7 and category 8 habitats, the faunal associations of tree holes, coconut shells and similar containers of plant origin certainly lie with the former rather than the latter. Although it is a far cry from the relatively clean water stored in a tin can or a dried-out coconut shell to the heavily organic water of some tree holes, a single species of mosquito (e.g., *Aedes polynesiensis*) often utilizes these two types of larval habitat and the whole range in between them. It is much less frequent, though, for the same species to utilize both tree holes and leaf axils. Thus Bick (1951), who recorded 47 species of mosquitoes from a total of 1,508 larval collections in New Guinea, listed 17 species from tree holes and other simple containers but only three from these habitats and leaf axils as well. *Aedes albolineatus*, typically a simple container breeder, was identified once from a swamp, 37 times from tree holes, 31 times from other simple containers and only twice from axils. A few mosquitoes do occur quite plentifully in both leaf axils and category 7 habitats. Thus some species of the African genus *Eretmapodites* breed in leaf axils, fallen leaves, tree holes and snail shells (Haddow et al., 1951), while in the Solomons *Uranotaenia quadrimaculata* larvae are most commonly found in *Alocasia* and *Coloecasia* axils but also occur in fallen leaves, coconut shells, tree holes and artificial containers (Belknap, 1953). Other species breed primarily in axils and only exceptionally in tree holes or artificial containers, for example *Aedes (Siegomyia) simpsoni* (Theob.) in Uganda (Haddow et al., 1951), while others again, including many species of *Tripteroides* and *Wyeomyia*, are restricted to leaf axils, often to those of specific plants, or to still more specialized containers such as *Nepenthes* pitchers. It is thus considered sounder from a biological point

of view not to regard epiphytic waters as an entity but to group tree holes and non-living containers of plant origin such as pods, husks and fallen leaves with other small simple containers, while viewing leaf axils as including the simpler types of a further category of water bodies. Although the water clogged in leaf axils is sometimes almost pure rainwater, it is fallacious to assume, as Thiemeann (1934) did, that this is necessarily always so. It is submitted that a logical sequence is traceable from leaf axils to such specialized habitats as *Nepenthes* pitchers, certain of the former standing in much the same relationship to the latter as do cans of clean water to heavily organic tree holes, the salient factor which determines the increasing identification of mosquitoes and other animals with more and more restricted habitats within this category being the increasing modification of the larval environment by fluids of plant origin.

Leaf axils were the only representatives of this category studied. Full collections were made from 39 axils, only 18 (46 per cent.) of which contained mosquito larvae. Many more axils than these figures indicate were actually searched for larvae in the case of islands from which no leaf axil breeders have ever been recorded. Thus the negative records for Ait, Aneityum, Uvea, Nukunono, Bellona, Tarawa and Funafuti are each based on the searching of at least 100 axils. The habitats examined were characterized as follows. -

Factor	Percentage occurrence.
Shade	100 per cent.
Foulness	41 "
Positive temperature factor	28 "

Sixty-two per cent. of the axils studied in detail contained remains of plant material. The water was sometimes quite clean and odourless, sometimes obviously fouled by decomposing plant material and sometimes noticeably influenced by secretions from the leaf base. Buxton and Hopkins (1927) pointed out that while the erect leaves of *Colocasia* direct much of the rainwater which falls upon them down the petiole into the axil, *Colocasia* leaves are reflected in such a manner that dew or rain falling upon them runs away from the axil and drips off the tip of the lamina, only the water which falls directly upon the petiole gaining access to the axil. They thus wondered whether the water in *Colocasia* axils is at least partly secreted by the plant, mentioning its slight sweet taste in favour of this suggestion. Field observations during the project showed that despite the shape of *Colocasia* leaves the axils are usually brimming over with water during heavy rain, but that when rain has not fallen for some time the fluid is small in amount, rather turbid and of a greyish colour. The hydrogen ion content, which is in the region of pH 6.8-7.0 immediately following rainfall, falls to the vicinity of pH 6.4. This increase in acidity is sometimes ascribable to the decomposition of fallen leaves, but it could be at least partly due to plant secretions. It is of interest in this connection that the mean pH value of the water for all the plant axils where readings were taken was 6.8, as compared with 7.0 for category 7 habitats. The water in *Freyinetia* axils is certainly influenced by plant secretions, and was always found to be of a pronounced pinkish colour. A similar observation was made in the case of *Cordyline terminalis* (coll. no. 731). Latex lethal to wédié larvae was reported from the axil water of travellers' palm and *Dracaena steudneri* Schweinf. in Uganda by Gibbins (1912).

The water in leaf axils is always shaded to some extent, and its temperature was found to be below that of the air in 72 per cent. of the collections for which data are available. Buxton and Hopkins (1927) made similar observations, and careful measurements by Haddow (1948) established that "larvae developing in a colocasia axil experience a remarkably stable temperature and that this temperature tends to be lower than that of the surrounding air." The transition from category 6-7-8 habitats is marked by a steady decrease in the temperature of the

water in relation to that of the air. The respective figures for a positive temperature factor in these habitats are 67 per cent., 46 per cent. and 28 per cent.

The faunal and floral indices of the leaf axils examined proved to be as follows.—

Faunal index	1	...	23	(59 per cent.)	.
	2	...	16	(41 " "	).
	3	...	0		
	4	...	0		
Floral index	1	...	38	(97 " "	).
	2	...	1	( 3 " "	).
	3	...	0		
	4	...	0		

As these figures indicate, the macrofauna of leaf axils tends to be rather more complex than that of small simple containers in the Pacific. The percentage occurrences of the individual groups of animals and plants represented are listed hereunder.

Animals	Protozoa	.....	.....	100 per cent.	.
	Diptera	.....	.....	69 "	"
	Entomostreaca	.....	.....	23 "	"
	Rotatoria	.....	.....	15 "	"
	Coleoptera	.....	.....	13 "	"
	Annulida	.....	.....	3 "	"
	Odonata	.....	.....	3 "	"
Plants	Microscopic algae	...	...	20 "	"
	Macroscopic algal masses	...	...	3 "	"

A lower percentage of the records for the Diptera concern Culicidae than in any of the other habitat categories. Eighteen axils proved to contain mosquito larvae, while nine others held developmental stages of Helicidae, Tendipedidae, Psychodidae, Tipulidae, Syrphidae and undetermined Cyclorrhapha. Heleids figured in nine collections, a typical leaf axil species being *Forcipomyia (Apelma) aff. comis* (p. 88). The Tendipedidae (*Tendipes* sp., *Pentaneura* sp. and an indeterminable larva referable to the Hydrobaeninae) were represented in four collections and the Psychodidae in three. Larvae and pupae of a species of *Telmatoscopus* (Psychodidae; recorded from Viti Levu (coll. no. 74<sup>1</sup>) were locally very abundant, being the dominant organisms in 100 *Colocasia* axils searched fruitlessly for mosquito larvae on that occasion. Larval Syrphidae figured in four collections, Tipulidae in two and undetermined cyclorrhaphids in two.

The only other insects found in leaf axils were coleopterous larvae of the genus *Helodes* (four collections) and a single damselfly nymph (Zygoptera) which was taken from a *Pandanus* axil in the uplands of Viti Levu (coll. no. 75<sup>1</sup>). These results are in general agreement with those of others who have investigated leaf axil faunas. Sweeney (1936) collected larval Heleidae, Psychodidae and Tendipedidae from *Freyeria* axils in Hawaii, and Williams (1936) reported damselfly nymphs from these axils, also from those of a species of *Cordyline*, in the same island group. Haddow (1948) referred to the abundance of psychodids in plant axils in Uganda, and stated that very occasionally small beetle larvae occur as well.

Quantitative studies of the ecology of the leaf axils of water-holding plants in the Pacific—particularly of indigenous forest species referable to *Freyeria*, *Cordyline* and other genera—would be of very considerable interest. Of all the mosquito larval habitats in the region these are the ones least subject to invasion by introduced animals, and comparative investigations of their biology in the various island groups might be expected to shed fresh light on problems of endemism and habitat

utilization. There was no time for such quantitative work during the present project, but on one occasion (following coll. no. 316) total counts of insects only were made from 122 successive *Freycinetia milnei* leaf axils near Suva, Fiji. Most of the water stored by this plant is contained in the tube-like structure formed by the bases of the innermost leaves of each head of foliage, and as already mentioned it is of a pinkish colour and obviously influenced by secretions. Fluid was always present, varying in quantity from a few cubic millimetres to about 5 cc. The total amount derived from the 122 axils in question was 150 cc., the average content of each axil thus being 1.23 cc. A total insect count gave the following results, the numbers in brackets representing the average numbers of individuals per axil.—

<i>Forcipomyia (Apelma?)</i> sp. prob. new (Heleidae) (To be described by Dr. W. W. Wirth, U.S. National Museum)	.....	506 larvae (1.15); 8 pupae (0.07)
Undetermined Syrphidae	.....	20 larvae (0.16)
<i>Aëdes (Finlaya)</i> sp. (Culicidae) (To be described separately)	.....	15 larvae (0.12)
<i>Telmatoscopus</i> sp. (Psychodidae)	.....	9 larvae (0.07)
Undetermined Tipulidae	.....	5 larvae (0.04)

Small crustaceans were collected from 23 per cent. of the axils studied, being much more evident than in category 7 habitats. An undetermined cladoceran was present in one collection and ostracods (*Cypridopsis* sp. and *Darwinula* sp.) in two. Copepoda were abundant in six collections, from *Colocasia*, *Cordyline* and *Freycinetia* in Viti Levu and from *Pandanus* in Tonga. In one instance (coll. no. 741) *Bryocyclops* sp. (Cyclopidae) and two members of the Harpacticidae, *Elaphoidella* sp. and *Phyllognathopis vigueri*, were associated in a single *Colocasia* axil. It is thought likely that scanty populations of Entomostacea might have escaped notice in at least some instances, and on the basis of the insect count detailed above it is obvious that the examination of larger numbers of axils at each collecting station would almost certainly have produced more records. Lang (1948) stated that some species of *Elaphoidella* are known only from leaf axils, while certain other harpacticids are not confined to this niche although they may often be found in it. He mentioned *P. riguieri* in this latter connection, giving records of this species from various bromeliads, *Cyrtandra*, *Colocasia* and *Nepenthes* as well as from *Sphagnum* moss and crannies in the earth. Haddow (1948) did not mention finding any crustaceans in the leaf axils which he studied in Uganda.

Rotifers were present in 15 per cent. of the collections, all but one of the records being referable to the Bdelloidea. This group too is more apparent than in category 7 habitats. Buxton and Hopkins (1927) noted the presence of rotifers in *Colocasia* axils in Samoa, while Wesenberg-Lund (1920-21) stated that "great quantities of Infusoria and some Rotifers" occur in *Angelica* leaf axils in Denmark.

The only remaining animals other than Protozoa recorded were small oligochaetes of the genus *Nais*, a few of which were present in a *Colocasia* leaf axil (coll. no. 78<sup>1</sup>) near Nandarivatu, Viti Levu. Haddow (1948) reported that small oligochaetes live in the debris at the bottom of large axils in Uganda, and that small free living nematodes often occur too. Planarians also occurred in some of his collections, and he listed several species of small tree frogs as quite common. Such frogs are altogether absent from the islands of the South Pacific.

Protozoans were always plentiful in leaf axils, particularly small protomonadiniid flagellates and holotrichous ciliates. Among the latter *Paramecium caudatum* and *Cyclidium* sp. were identified, while the flagellates included several cosmopolitan species, *Bodo vaudatu*, *Monodinium incurvum*, *Chilomonas paramecium*, *Phacus pleuronectes* and *Trachelomonas hispida*. Undetermined species of *Astasia* and

*Monas* were also noted. While colourless flagellates were often very common indeed, phytoflagellates were less evident than in polluted surface water. One rather surprising record was that of an undetermined heliozoan from a *Colocasia* axil (coll. no. 711). Diatoms were present in small numbers in some of the larger *Alocasia* and *Colocasia* axils, and were probably there quite adventitiously having been washed in by rain. Fungal spores were always present, and where the organic content of the water was high (e.g., coll. no. 316) yeasts and bacteria abounded. There was thus no shortage of potential larval foods in these axils in which plant secretions, too, may be of significance in the nutrition of mosquito larvae. Larval gut contents reflected the availability of organic and inorganic matter in the habitat concerned, and fungal spores were always present in quantity. A high percentage of the larvae proved to have ingested insect hairs and scales and various chitinous particles of arthropod origin. Among the latter were crustacean remains, and as noted earlier cyclopids were particularly abundant in the absence of mosquito larvae which suggests that they may be preyed upon to some extent at least. Predacity is highly developed among leaf axil larvae, and even non-predaceous species such as *Uranotaenia quadrimaculata* were often found to have ingested portions of head capsules, hairs and other structures of their own kind. Bates (1949) mentioned similar observations concerning larvae in over-crowded laboratory jars. Moulted larval skins must very frequently be eaten by developing larvae purely as a consequence of non-selective feeding under the very confined conditions of life in category 8 habitats, and this suggests an explanation for the development of predaceous habits on the part of so many specialized container mosquitoes.

Buxton and Hopkins (1927) referred to the common occurrence of flagellates and holotrichous ciliates in Samoan *Colocasia* axils, and Haddow (1948) recorded ectocommensal Peritricha—conspicuous by their absence from the Pacific leaf axils examined (p. 117)—as well as free living Holotricha from this habitat in Uganda. Both Buxton and Hopkins and Haddow noted the presence of diatoms, the latter author stating that these, together with mobile unicellular algae and yeasts were abundant.

Eight species of mosquitoes were collected from leaf axils.—

SPECIES	NUMBER OF TIMES COLLECTED			Total
	Rare	Common	Abundant	
<i>T. matheoni</i>	..	1	—	5
<i>A. samoanus</i>	..	1	—	5
<i>A. (Hindluya) sp.</i>	..	4	—	4
<i>U. quadrimaculata</i>	..	1	1	3
<i>T. folicola</i>	..	—	1	1
<i>A. tongae</i>	..	—	1	1
<i>C. perkini</i>	..	1	—	1
<i>Corethrella</i> sp.	..	1	—	1
Totals	..	12	5	21

Only one of these species, *Aedes tongae*, primarily breeds in small simple containers. The single record concerns a number of young larvae which were found in 100 cc. of fresh, clean rainwater (PII 7-0) in a *Pandanus* axil at Sikaiana (coll. no. 287). The larvae of *A. samoanus* almost invariably occur in *Alocasia* and *Colocasia* axils (Buxton and Hopkins, 1927), although there are occasional records from *Pandanus* (O'Connor, 1923; Bohart and Ingram, 1946) and wild *Canna* and pineapple (O'Connor, 1923). My record of this species from a tree hole (coll. no. 169) appears to be the first from such a habitat. *Uranotaenia quadrimaculata*, as noted in the preceding section, breeds readily both in axils and small simple containers. This is a relatively rare phenomenon, although occasional crossings of the borderline between category 7 and 8 habitats are not uncommon. Where these concern species that primarily breed in simple containers, the axils selected

are usually large ones in which the larval environment is not very unlike that afforded by the customary habitat. Thus the Fijian *Aedes pseudoscutellaris*, which characteristically breeds in a wide variety of large and small simple containers, is sometimes reported from *Alocasia* axils (Paine, 1943). As much as a litre or so of water may be cupped in these, the bases of the large and massive petioles usually curving out from the area of attachment in such a manner that ovipositing mosquitoes have easy access to many square centimetres of water surface. Similar conditions may prevail in the case of the larger species of *Pandanus*, the axils of which often retain water for only brief periods following rain and then dry up completely. The conditions prevailing in such habitats in the earliest postpluvial period must closely resemble those in simple containers holding fresh rainwater. Conversely, it is understandable that *Aedes samoanus* and other mosquitoes which exhibit a similar preference for the more generalized kinds of category 8 habitats invade simple containers on occasion.

The heaviest larval populations tend to be found in these borderline species. Thus *U. quadrivittata* larvae were abundant in the complete absence of predators in one *Alocasia* collection (no. 218, Guadalcanal), while *A. samoanus*, which as Buxton and Hopkins (1927) observed never seems to be exposed to predation, was noted as abundant in three of my five collections, two from *Alocasia* and one from *Cocosea*. The more confined axil habitats are, however, the smaller does the number of larvae present tend to be. Thus, for example, more than three larvae of the species of *Aedes* (*Finlaya*) herein recorded from *Freycinetia* in Viti Levu were never collected from a single axil, the average water content of these axils being a little over 1 cc. These larvae are neither predaceous nor subject to predation by other animals, and it would be of considerable interest to learn how many eggs are laid in each axil by the adult female. Belkin (1953) drew attention to the fact that he never found mosquito egg rafts in water collections in living plants in the Solomons, and considered it likely that eggs of mosquitoes in such habitats are laid singly in all genera including *Uranotaenia* and *Culex*. A further extension of such specialization might well involve interrupted oviposition, only a few eggs being laid in any one small axil. The species of *Aedes* (*Finlaya*) under consideration exhibits a behaviour pattern which must be most advantageous to a leaf axil breeder. Its larvae "crawl" quite rapidly over both damp and dry surfaces. O'Connor (1923) and Buxton and Hopkins (1927) made similar observations with regard to *A. samoanus*, the latter authors (their Text-fig. 27) publishing sketches of the tracks followed by larvae of this species on wet and damp blotting paper. A larva of the Fijian species, which was placed on a piece of wet blotting paper on the laboratory bench, took one minute to follow a circuitous 5 cm. track to the edge of the paper. It then struck off along the dry bench top, and at the end of a further four minutes had crawled another 21 cm. and down over the edge. Clinging there for a few seconds with the anterior part of the body hanging freely suspended and swaying slightly, it suddenly threw itself clear with a convulsive movement and fell onto my hand 10 cm. beneath. Retuned to the bench top, the thin film of water which was still adhering to its body was removed with blotting paper. It then made a sequence of vigorous curving and straightening movements, on two occasions hurling itself just clear of the surface of the bench. O'Connor (1923) noted that *A. samoanus* larvae can spring in this fashion for half an inch or more, but Buxton and Hopkins (1927) were unable to confirm this from their own observations. As O'Connor first suggested, these unusual powers must enable such larvae to quit drying leaf axils and move to others containing sufficient fluid for their needs.

Cannibalism and predation on the part of certain mosquito larvae afford further reasons for the limitation of the numbers of larvae in leaf axils. These habits are general in the subgenus *Rachisoura* of *Tripteroides*, and Belkin (1950) stated with regard to *T. mathesonii* that late instars are usually found singly or at most three to four per axil. My observations are in agreement with this. *Cochlerella* larvae are

likewise highly predaceous, and only two were present in 120 cc. of water in a *Pandanus* axil from which the genus was recorded in Guadalcanal (coll. no. 222). The evidence indicates that conditions of overcrowding and underfeeding have favoured the development of predacity in diverse groups of mosquitoes. As Bates (1919) has pointed out, even larvae which are normally non-predaceous may modify their habits under these conditions. It has, for example, been observed in New Britain that second- and later instars of *Anopheles punctulatus* congregate about hatching eggs of their own species and eat the emerging larvae in both crowded laboratory containers and crowded transient pools (Laird, 1946). All the mosquitoes listed by Bates as actively predaceous primarily breed either in transient pools or in simple or specialized containers. As already noted predation by other animals is at a minimum in these habitats, and this very fact, by favouring the development of heavy mosquito larval populations, has in turn favoured the acquisition of predaceous and cannibalistic habits by mosquito larvae. Every stage in the development of predacity is exhibited by various leaf axil breeders, from such species as *Uranotaenia quadrimaculata* which adventitiously ingest portions of cast larval skins of their own kind to others, like *Toxorhynchites* spp. and *Eretmapodites* spp., which habitually seek out and destroy larvae of their own or other species less powerful than themselves. An intermediate stage has been described for the most easterly leaf axil predator in the Pacific, *Uranotaenia colocasiae* Edwards, larvae of which do not actively seek out prey but nevertheless hold on to and consume weaker larvae with which they come into direct contact (Paine, 1943).

Another adaptation of life in category 8 habitats (and in small simple containers as well) is the habit of lying inert at the bottom for extended periods. The explanation for this may be bound up with the relative slowness of the metabolic rate consequent on the lengthy larval life of leaf axil mosquitoes. Haddow (1948) suggested that the slow development of such mosquitoes may be due to the low and stable temperatures prevailing in axils. Long periods of inactivity must certainly be of decided advantage to non-predaceous larvae, which run a greater risk of being detected by enemies whilst moving through the field of perception of the latter.

Hairiness is commonly apparent in specialized container breeders just as it is in tree hole larvae. Setting aside the question of the effect of environmental influences upon the development of hairs, unusual hairiness confers certain advantages upon the larvae concerned. First of all, the majority of these tend to rest on their backs while feeding or simply lying at the bottom. It would appear that the thick and elongate hairs of the body and of the caudal and siphonal tufts are of service to them in keeping the body braced off from the surface of the finely divided bottom debris which is characteristically present, thus enabling them to remain balanced without effort in a zone rich in free swimming flagellates, ciliates and bacteria. Secondly, on being alarmed these larvae usually plunge down into the bottom debris, which affords them their only shelter in such habitats—the occurrence of masses of filamentous algae, as in coll. no. 223, being regarded as very exceptional indeed. There is often great difficulty in siphoning larvae out of axils once alarmed, without repeated flushings with fresh water. It is probable that their stiff, branched hairs help them at this time by enabling them to brace themselves in the narrowest crannies at the bottom-most limit of the leaf axils. Similar behaviour under natural conditions must assist larvae which cannot move freely over exposed surfaces to maintain themselves in the deepest parts of axils where a film of fluid persists even after the rest of the contents have evaporated away.

Haddow (1948) found no chloride whatsoever in taro axils, which is not surprising in view of the fact that the anal papillae of mosquito larvae reach their greatest development among specialized container breeders. The leaf axil larvae of two species of *Culex* (*Acalyptum*) (e.g., *C. perkinsi*) have papillae which

are not only enormously elongate but exhibit a marked constriction part-way along the length (Stone and Penn, 1948), and I have noted similar constrictions in the great sausage-shaped anal papillae of larval *U. quadrifasciata* from leaf axils.

9. BRACKISH LAKES AND PONDS. Twenty-five habitats referable to this category were seen, all but one of them—Lake Tenggano, Rennell, being ponds. Only four (16 per cent.) were negative for mosquitoes. A typical brackish pond, subject to intermittent inundation with sea water and to repeated dilution by rains, is illustrated in Fig. 59 (coll. no. 333, Queensland).

Sea water is of distinctly alkaline reaction, its pH value generally lying between 7.9 and 8.3 and usually ranging from 8.1 to 8.2 according to Feldmann (1951). The hydrogen ion content of brackish ponds is largely influenced by the presence of sea water in varying proportions, and tends to be more stable than does that of freshwater ponds. Only one of the brackish ponds studied (coll. no. 315) was of acid reaction. This had a pH value of 6.2, a fact which may have been due to the presence of large quantities of decaying eucalypt leaves. The mean value for all the ponds concerned was pH 7.8, and all but four of the 25 readings lay within the range pH 7.4–8.4.

Just as the presence of a high proportion of chlorides is the chief physical factor differentiating brackish ponds from freshwater ones, variation in the proportion of chlorides is the factor most intimately bound up with degrees of adaptation to the former on the part of aquatic animals and plants. In other respects there is considerable superficial resemblance between the two habitats. The bottom is usually composed of mud or sand (category 1, 77 per cent.; category 9, 88 per cent.) and in some cases is covered with dead leaves (category 1, 21 per cent.; category 9, 12 per cent.). The vegetation of brackish ponds tends to be less complex than that of freshwater ones, and shade is thus less pronounced in ponds located, as were most of the ones examined, in open places (category 1, 73 per cent.; category 9, 60 per cent.). In both types of habitat the temperature factor was high (category 1, 83 per cent. positive; category 9, 91 per cent. positive) and there was evidence of fouling by animal pollution or plant decomposition in about half of the ponds seen (category 1, 51 per cent.; category 9, 48 per cent.).

The faunal and floral indices of the brackish ponds dealt with proved to be as follows.—

Faunal index	1	...	...	...	6	(24 per cent.)
	2	...	...	...	14	(56 " "
	3	...	...	...	3	(12 " "
	4	...	...	...	2	( 8 " "
Floral index	1	...	...	...	13	(52 " "
	2	...	...	...	12	(48 " "
	3	...	...	...	0	
	4	...	...	...	0	

These indices are very much lower than those of freshwater ponds. Forty-eight per cent. of the latter had a faunal index of 3 or 4, the relevant figure for category 9 habitats being 20 per cent. Similarly, only 48 per cent. of the brackish ponds had a floral index of 2, as compared with 89 per cent. of the freshwater ones.

The various groups of animals and plants occurring in brackish ponds were collected in the following order of prevalence.—

Animals	Diptera	.....	.....	.....	84	per cent.
	Hemiptera	.....	.....	.....	52	" "
	Odonata	.....	.....	.....	44	" "
	Protozoa	.....	.....	.....	38	" "
	Coleoptera	.....	.....	.....	36	" "
	Mollusca	.....	.....	.....	16	" "

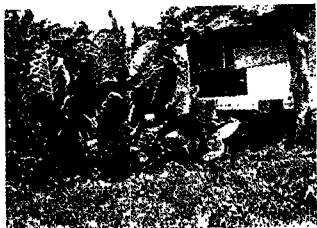


FIG. 5. Container habitats. Simple containers: natural drain and derived root guttering and specialized containers: deer excreta. *Marquesas*, Laulau, Upolu, Western Samoa.



FIG. 59. Transient brackish pool, Bucasia Beach, near Cairns, North Queensland, Australia.

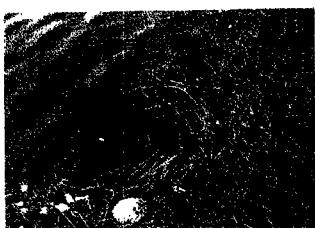


FIG. 61. Edge of tidal inlet; near Huncoson Anchorage, Guadalcanal, British Solomon Islands Protectorate.

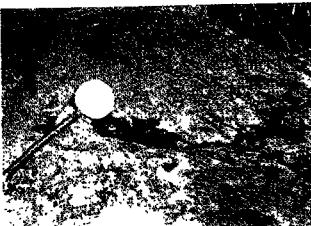


FIG. 53. Crevice in boulders, Taloma River, General Camp, Bougainville, Solomon Islands Protectorate.



FIG. 93. Eddi stream, Andavadoaka, Androy, New Hebrides.



FIG. 62. Salt marsh, Aue Vata, near Nosamea, New Caledonia.

	Entomostraca	....	....	12	"	"
	Malacostraca	....	....	12	"	"
	Arachnida	....	....	8	"	"
	Pisces	....	....	8	"	"
	Rotatoria	....	....	8	"	"
	Amphibia	....	....	4	"	"
	Plecoptera	....	....	4	"	"
Plants	Microscopic algae	....	....	100	"	"
	Grasses, sedges, reeds	....	....	11	"	"
	Macroscopic algal masses	....	....	12	"	"
	Aquatic phanerogams	....	....	8	"	"

Mosquito larvae were present in all 21 habitats positive for Diptera. Larval Tendipedidae (*Tendipes*, *PolyPEDilum*, *Pentaneura*) were also present in four instances, Heleciidae (*Culicoides* sp.) in one and Stratomyiidae in one. Chironomids are well known from brackish water (Carl, 1937, etc.) and Lambert (1930) recorded *Stratiomyia* sp. from marsh ditches of the Thames Estuary. Séguy (1950) stated that stratomiid larvae commonly occur in brackish marsh pools of the Holarctic Region, feeding mainly on detritus and flagellates.

The order Hemiptera was well represented, records being obtained from 52 per cent. of the brackish ponds as compared with 59 per cent. of the freshwater ones. The Veliidae, Mesovelidiidae and Gerridae were all collected, the four species specifically identified—*Limnogonus australis*, *L. pacificus*, *Microvelia oceanica* and *M. peramoena*—being taken from category 1 and other freshwater habitats as well. A gerrid of primarily marine affinities belonging to the genus *Halovelia* was common on a large pond of high salt content at Uvea (coll. no. 24<sup>1</sup>). This pond, one of several of the sort at the atoll, appears to be a former reef pot hole or a limestone sink. Although now surrounded by jungle it is within 100 metres of the sea with which it is possibly still connected by underground crevices. Its diameter was not measured but appeared to be in the vicinity of 80 metres, while its depth near the edge had been plumbod by the local gendarme, M. Blanchard, at 35 metres. Eight of the 21 species/records of Hydrometridae were from category 9 habitats, *Hydrometra risbeci* and *H. halei* both being taken from fresh water as well. Sub-surface hemipterans of the families Notonectidae, Corixidae, Nepidae and Belostomatidae were also represented. Williams (1936) found corixids to be common in brackish ponds in Hawaii, while Carl (1937) referred to their abundance in this situation in Canada. Lambert (1930) reported *Notonecta* sp. from English marsh ditches.

Odonata are less common in brackish water than in fresh water. Ten of my 15 species records were referable to the Zygoptera and five to the Anisoptera. Carl (1937) referred to the presence of zygopteran nymphs in considerable numbers in Canadian brackish ponds. Water beetles were likewise rarer in the brackish ponds studied. Seven of the nine collection records concerned the Dytiscidae, one the Gyrinidae and one the Hydrophilidae. Three of the five species of dytiscids and the gyrnid were also collected from freshwater ponds and pools. An interesting feature was the collection of the dytiscid *Canthidrys serialis* from Lake Tenggano, Kennel (coll. no. 250), and from a salt marsh (coll. no. 138) at Uvea. Lambert (1930) and Williams (1936) both mentioned the prevalence of hydrophilids in brackish ponds. The only one of these beetles which I found in such a habitat, *Paracymus pygmaeus*, is known elsewhere from fresh water (Balfour-Browne, 1915).

The Mollusca and Entomostraca were of less frequent occurrence in brackish than in fresh water. Certain pond snails exhibit quite a wide range of tolerance as regards chlorides and Carl (1937) spoke of freshwater species of *Physa* and *Lymnaea* as invading brackish water in Canada. Two species specifically identified,

*Melania mageni* and *Physastra tetrica* were found in freshwater habitats as well as in category 9 ponds.

Only two malacostracans from brackish ponds could be identified as to species. One of these, the decapod *Caridina nilotica* (prob. var. *meridionalis* Roux), is usually found in fresh water, while the amphipod *Paracalliope* sp. is considered by Dr. D. E. Hurley to be most probably referable to *P. fluviatilis*, which occurs in both fresh and brackish water. Perhaps the most interesting of the remaining records is that of *Bufo marinus* tadpoles from a brackish pond (coll. no. 345) north of Cairns.

Protozoans were much less apparent (38 per cent.) than in freshwater ponds (96 per cent.), but diatoms and other unicellular algae were always present. Diatoms were particularly abundant and varied, and always made up a major part of the gut contents of larvae from category 9 ponds.

Only six species of mosquitoes were collected from these habitats.—

TABLE XXX

SPECIES	RARE	NUMBER OF TIMES COLLECTED			TOTAL
		COMMON	ABUNDANT		
<i>C. annulirostris</i>	.	3	3	8	11
<i>An. farauti</i>	..	4	1	2	7
<i>C. siliens</i>	..	1	1	2	4
<i>A. vigilax</i>	..		1	2	3
<i>Az. catasticta</i>	..	1		1	2
<i>C. squamosus</i>	..		1		1
TOTALS	..	9	7	15	31

*C. squamosus* larvae were common in thick *Spirogyra* masses in quiet water into which a spring discharged at the edge of Lake Tengano, Rennell (coll. no. 250), and *Aedomyia catasticta* was present in abundance among masses of *Spirogyra pseudoneglecta* which almost filled a brackish pond (coll. no. 341) at Cairns Airfield. Another brackish pond located only a few feet from the last, but containing no filamentous algae, yielded but two *Az. catasticta* larvae. These two Queensland ponds had a similar substratum and they were visited towards midday of the same day when the temperature in each case was 23°C. It is of interest that while the hydrogen ion content of the bare pond was pH 7.8, that of the one in which active photosynthesis was proceeding in consequence of the heavy concentration of algae was pH 9.5. It would appear that in both Rennell and Queensland the abundance of filamentous green algae had outweighed the factor of salinity in the selection of these habitats by the two primarily freshwater mosquitoes concerned.

*Culex siliens* and *Aedes vigilax* are both found breeding most frequently in brackish water, category 9 and 10 habitats being used commonly by the former and virtually exclusively by the latter. For all that, the mosquitoes most commonly recorded from category 9 habitats were the ubiquitous *C. annulirostris* and *Anopheles farauti*.

The macroflora of the brackish ponds examined was poorly developed by comparison with that of the freshwater ones. Sedges and grasses made up the bulk of the phanerogams, and although macroscopic algal masses were as evident as in category 1 habitats overall plant shelter was generally less available than in the latter. Thus 52 per cent. of the category 9 habitats had a floral index of 1, the relevant figure being only 10 per cent. for freshwater ponds. To offset this, mosquito enemies were of less frequent occurrence in the former, as has been indicated. The figures for larval abundance are substantially higher than in the case of category 1 ponds, 22 (71 per cent.) of the 31 species collections being registered as common or abundant as compared with 57 per cent. of those from freshwater ponds. Larval abundance was, indeed, as marked in the category 9 ponds studied as in transient pools.

As regards larval associations, *An. farauti* and *C. annulirostris* were found breeding together at Aneityum on three occasions and in Queensland on two. These two species also occurred together with *C. squamosus* at Lake Tenggano. *C. sitiens* and *A. vigilax* were found associated on one occasion in New Caledonia, and in one of the Queensland collections both these mosquitoes were taken in company with *An. farauti*.

Primarily brackish water larvae such as those of *C. sitiens* and *A. vigilax* are characterized by a marked reduction in size of the anal papillae. The papillae of these species are very short and globate, those of *C. sitiens* at least remaining so even under freshwater conditions (coll. no. 85). Where such primarily freshwater but ubiquitous mosquitoes as *C. annulirostris* and *An. farauti* develop in brackish water, their larvae have much shorter papillae than is normal. Thus the length: breadth ratio of the anal papillae of *C. annulirostris* larvae from freshwater habitats is normally in the vicinity of 4:1, but it was as low as 2:1 in larvae from a brackish pond at Aneityum (coll. no. 106). Even where the papillae are so short as to be comparable in size with those of *C. sitiens*, though, they still remain distinctly pointed.

10. SALT MARSHES, MANGROVE SWAMPS, TIDAL STREAMS AND ESTUARIES. Eighteen habitats belonging to this category were examined, only two of them being without mosquito larvae. Collections were made from 12 salt marshes (Fig. 62), four mangrove swamps, a tidal stream (Fig. 60) and a tidal inlet (Fig. 61).

All these habitats differ from brackish ponds in two respects. Firstly, they are in continuous contact with the sea or else this contact is only broken at low tide. Secondly, they are characterized by a dominance of emergent or marginal vegetation. Although their salinity is subject to variation because of evaporation, it tends to approximate that of the sea more closely than does that of brackish ponds. While the hydrogen ion content is likewise variable, and the reaction of one salt marsh (coll. no. 44) was acidic (pH 5.2) because of the decomposition of a stranded algal sheet, the mean pH value for the 18 category 10 habitats studied, 7.9, was 0.1 higher than that for the category 9 habitats.

Too little data are available for these collections to make full discussion worthwhile. The characteristic mosquitoes were those common in brackish ponds (*Culex annulirostris*, *C. sitiens*, *Aedes vigilax* and *Anopheles farauti*), the only other record being an adventitious one of *C. pipiens fatigans* (coll. no. 58, New Caledonia). The other insects collected also had close affinities with those of category 9 habitats. Other Diptera found in both brackish ponds and the habitats under discussion were referable to the Stratiomyidae, Tendipedidae and Heleidae, while nymphs of Odonata were of comparable abundance in both cases. All the families of Hemiptera recorded from brackish ponds were found to be represented in category 10 habitats, with the exception of the Nepidae and Corixidae; while the Pleidae were recorded from the latter breeding places but not from the former. Finally, of the five species of beetles found in category 10 habitats, four *Hydatocerus consanguineus*, *Limnoderessus compactus*, *Bidessus cheesmanae* and *Canthydrus serialis*—also figured in brackish pond collection.

Salt marshes and allied habitats are, like freshwater swamps and marshes, characterized by an abundance of marginal and emergent vegetation. All those seen had a floral index of 2, the mosquito larvae concerned always having available plant shelter whether afforded by phanerogams or by masses of filamentous algae. For all that, though, the percentage of mosquito species/collections registered as common or abundant was just as in brackish ponds, 71 per cent.

On the grounds of my evidence, therefore, there is little reason for subdividing surface brackish water into two categories. However, Bates (1919) saw fit to consider all brackish water accumulations under two headings, "brackish marshes and swamps" and "small accumulations of brackish water", distinguishing the first from the second on the grounds of their larger size and using shade and salinity

*aibolineatus* and *A. s. scutellaris*, are primarily container breeders. *Culex halifaxi* utilizes quite a wide range of larval habitats and was found elsewhere in large and small simple containers, while *C. fraudatrix* is primarily a surface water breeder (Perry, 1946; Bick, 1951) which nevertheless often breeds in natural and artificial containers as well (Belkin, 1955; Bick, 1951). This last species flourishes in the latter types of habitats in the absence of other breeding places on both Bellona and Rennell.

*Anopheles farauti* almost always utilizes surface waters as larval habitats, as for that matter do all the Pacific anophelines. Thus, of the 58 collections in which *An. farauti* figured during these studies, only three were made from containers—a rock crevice on Espiritu Santo (coll. no. 36), a 11 gallon drum on Guadalcanal (coll. no. 276) and a halved coconut shell on Aore (coll. no. 13). The only mosquitoes which have succeeded in establishing themselves on Bellona are either primarily container breeders or else species which in other places readily utilize containers as larval habitats. It is thus considered that while occasional collections of *An. farauti* larvae might from time to time be found in container habitats at Bellona were sufficient surface water habitats available there for the maintenance of a heavy population of this mosquito, the lack of surface water precludes its establishment from taking place.

Tutuba, New Hebrides ( $15^{\circ}35'S$ ,  $167^{\circ}17'E$ ), is anopheline-free although only three kilometres away from Aore and the same distance from the southwest coast of Espiritu Santo, in both of which places *An. farauti* is abundant. This small island was visited during August, 1952, and as already described in detail (p. 58 ff.) it was found to lack surface water accumulations with the exception of duckweed-covered forest ponds. The low-lying coral platform of the northern part of Tutuba is so porous that transient pools are not formed during dry season showers, although it is possible that such pools may exist to a limited extent under wet season conditions. The permanent establishment of *Anopheles farauti* on the island is rendered most unlikely because of the thick covering of *Spirodela* on the only ponds which persist through the dry season.

Turning now to the southern perimeter of the malarious zone, anopheline-free Futuna lies about 65 kilometres from malarious Ancityum to the S.S.W. and from malarious Tanna to the west. Futuna, the most easterly island of the New Hebrides, is a Polynesian outlier and has long had the reputation of being a healthy island at the edge of a highly malarious zone. Steele (1880) stated that "some of the missionaries have called it 'the Madeira of the New Hebrides' and have advocated its claims as a sanatorium for those resident on the other islands," while Paton (1894) referred to it as seeming "so home-like and healthy, having no fever and ague."

Mills (1954) undertook a thorough malaria survey at Futuna during November, 1952, taking blood films from 286 of the 294 islanders. All of these preparations were negative for *Plasmodium*, and Mills also reported that the spleen index was nil. He noted the presence of seepages (often brackish) and small streams and felt that as these are permanent surface water sources there must be some ecological factor which makes Futuna an unsuitable location for *An. farauti*.

My wife and I visited Futuna from February 19 to 23, 1953, at the height of the wet season. We located and studied a total of 15 water bodies, only two of which did not contain mosquito larvae. Ten of these habitats were referable to container categories (6, 7, 11), while four transient pools and a ponded stream were located. It is probable that numerous stream-bed ponds are formed under dry season conditions. Three of the transient pools held developmental stages of primarily container-breeding mosquitoes, *Aedes s. scutellaris* (twice) and *Tripteroides melanostigma* (once). Two of these in addition contained larvae of *Aedes vexans nocturnus*, an exclusively surface-water breeder not previously recorded from the island. No larvae were present in the remaining transient pond or in the ponded stream (coll.

As regards larval associations, *An. farauti* and *C. annulirostris* were found breeding together at Aneityum on three occasions and in Queensland on two. These two species also occurred together with *C. squamosus* at Lake Tenggano. *C. sitiens* and *A. vigilax* were found associated on one occasion in New Caledonia, and in one of the Queensland collections both these mosquitoes were taken in company with *An. farauti*.

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Too little data are available for these collections to make full discussion worthwhile. The characteristic mosquitoes were those common in brackish ponds (*Culex annulirostris*, *C. sitiens*, *Aedes vigilax* and *Anopheles farauti*), the only other record being an adventitious one of *C. pipiens fatigans* (coll. no. 58, New Caledonia). The other insects collected also had close affinities with those of category 9 habitats. Other Diptera found in both brackish ponds and the habitats under discussion were referable to the Stratiomyidae, Tendipedidae and Heleidae, while nymphs of Odonata were of comparable abundance in both cases. All the families of Hemiptera recorded from brackish ponds were found to be represented in category 10 habitats, with the exception of the Nepidae and Corixidae; while the Pleidae were recorded from the latter breeding places but not from the former. Finally, of the five species of beetles found in category 10 habitats, four—*Hydatocerus sanguineus*, *Limboitesus compactus*, *Bidessus cheesmanae* and *Canthydrus seridis*—also figured in brackish pond collection.

Salt marshes and allied habitats are, like freshwater swamps and marshes, characterized by an abundance of marginal and emergent vegetation. All those seen had a floral index of 2, the mosquito larvae concerned always having available plant shelter whether afforded by phanerogams or by masses of filamentous algae. For all that, though, the percentage of mosquito species/collections registered as common or abundant was just as in brackish ponds, 71 per cent.

On the grounds of my evidence, therefore, there is little reason for subdividing surface brackish water into two categories. However, Bates (1949) saw fit to consider all brackish water accumulations under two headings, "brackish marshes and swamps" and "small accumulations of brackish water", distinguishing the first from the second on the grounds of their larger size and using shade and salinity

as the primary criteria for subdivisions within each category. A valid classification of the smaller water bodies must be applicable to all kinds of animals and plants, not just to mosquitoes. It is likely that the fact of salinity is the criterion on which the invasion of all kinds of brackish water accumulations by mosquitoes must hinge, but for all that the more intimate connection of category 10 habitats with the sea must make for a more marked infiltration of primarily marine elements into their fauna and flora. For example, the marine fishes *Acanthurus triostegus*, *Pomadys opercularis* and *Stigmatogobius duospilus* were never collected from any habitat other than a tidal stream at Ancityum (coll. no. 95). Rather than lump the two types of habitat together it is considered preferable to recognize the existence of two distinct categories as providing a sounder basis for more detailed faunal and floral studies.

II. SIMPLE BRACKISH CONTAINERS. Fourteen habitats within this category were studied, all but one of them containing mosquito larvae. Eight of the containers were beached vessels, the water in all of these being appreciably diluted with rainwater. The remaining six, four of which were rock holes in the lower spray zone and two of which were truck tyres subject to inundation at high tide, held water of much higher salt content.

The physical conditions prevailing in these habitats resembled those of category 6 and 7 containers, the single important point of difference being the presence of a varying degree of salinity. Thus rainwater so dilutes the small amounts of seawater remaining in the bilge of some beached canoes that the salt content falls to a low level, and the fauna is very like that of simple freshwater containers. Predators were found to be rare, larval Odonata occurring in but two instances, while Diptera were always plentiful. In addition to mosquito larvae, *Tendipes* sp. (Tendipedidae) was noted twice and *Dasyhelea* sp. (Heleidae) once. The only animals other than mosquito larvae found in the strongly saline pools were hermit crabs (*Pagurus* sp.) and prawns of marine affinities (*Palaeomon* aff. *debilis*). Nine species of mosquitoes were collected.—

TABLE XXXI

SPECIES	NUMBER OF TIMES COLLECTED			Total
	Rare	Common	Abundant	
<i>C. sitiens</i>	—	—	—	6
<i>A. s. scutellaris</i>	—	1	1	4
<i>A. polynesiensis</i>	—	—	2	2
<i>C. annulirostris</i>	—	—	—	2
<i>T. melanopterus</i>	—	—	1	1
<i>A. albimanus</i>	—	—	1	1
<i>A. albofasciatus</i>	—	—	—	1
<i>C. fraudatrix</i>	—	—	—	1
<i>C. pipiens fatigans</i>	—	—	—	1
Totals	—	1	7	19

All but three of these species breed primarily in simple containers filled with fresh water, from which they have succeeded in invading the habitat under consideration without any intermediate adjustment to brackish conditions. *C. sitiens* larvae, though, are almost always found in brackish water and occur more frequently in containers—especially those of high salt content—than in surface water. Bohart and Ingram (1946) mentioned collecting larvae of this mosquito “along the shores of various Pacific islands in coral crevices and boats containing brackish to highly saline water.” *C. annulirostris* and *C. fraudatrix*, both primarily surface water breeders, could reach this type of habitat by way of either freshwater containers or brackish ponds and marshes. The single record of the latter species is from Belona (coll. no. 238), where it utilizes container habitats in the absence of surface water; Bick (1951) quoted Knight et al. for reports of *C. fraudatrix* from mangrove pot holes.

Brackish containers are favourable habitats for mosquitoes the larvae of which can tolerate salinity, whether these are primarily freshwater container breeders or brackish water breeders. Specialization takes the form of adaptation to increasing degrees of salinity. Thus, while all nine of the species recorded were collected from beached canoes, only *C. sitiens* (four times) and *A. s. scutellaris* (once) were ever found in spray zone pools or artificial containers subject to frequent inundation. Through evaporation, the salinity of the water in these latter types of habitat may come to exceed that of seawater.

12. SPECIALIZED BRACKISH CONTAINERS. No special attention was paid to these, my only record being of *C. annulirostris* larvae from a flooded crab hole at Tarawa (coll. no. 306). As crab holes are the only specialized derivatives of simple brackish containers, and are the sole larval habitat of the New World mosquitoes of the genus *Deinocerites* and the favoured breeding place of *Aedes (Skusea)* in the Pacific, there are grounds for following Bates (1919) in considering them as forming a distinct habitat class. It is likely that they were initially utilized by mosquitoes which had become adapted to breeding in such habitats as the tree holes receiving salt spray from which Bick (1951) collected larvae of *A. (Skusea) dasyorrhinus* King and Hoogstraal in New Guinea.

#### FACTORS INFLUENCING THE DISTRIBUTION OF ANOPHELES IN THE SOUTHERN PACIFIC.

To return now to the question raised in the Introduction, as to whether an ecological barrier is operating to keep *Anopheles* from becoming established in the anopheline-free islands of the Pacific.

It is proposed to consider the anopheline-free islands of the generally malarious Solomons and New Hebrides first of all. The period August 15–17, 1953, was spent at Bellona ( $11^{\circ}18' S$ ,  $159^{\circ}48' E$ ), a raised atoll only 31 kilometres northwest of Rennell, where both *An. farauti* and malaria occur. The visit took place during a wet period, heavy rain falling during each night. Neither Lambert (1931) nor Black (1952) found anophelines on Bellona, and the latter author found neither enlarged spleens nor positive blood films among 116 people who had never left the island. Black found one immigrant Guadalcanal child to be parasitized by *Plasmodium malariae*, and reported palpable spleens for a number of repatriated islanders and Melanesian newcomers.

Blood smears were taken from 17 children between the ages of a few months and 10 years, none of whom had ever left Bellona, during the present investigation. All these preparations were negative for malaria parasites. The length and breadth of the island were traversed in a search for mosquito breeding places. At Ahanga, the landing place on the north-east coast, there are no spring-fed coral pools such as occur at Lavangga and Te Uhungango, Rennell. The only accumulation of (brackish) surface water that could be found there was one in a cave in which Black (1952) had failed to find larvae. The islanders are in the habit of washing their clothes in this cave, and the water surface bore a soapy scum inhibitory to mosquito breeding. As Black pointed out, the porous nature and coral basis of the black soil of the former lagoon in the central part of this small island precludes the formation of surface pools. The ground does not hold any water within an hour or two of the end of a shower of rain. The only mosquito breeding places recorded by Black were two coral holes, coconut shells, metal drums and canoes. There are no wells on the island. Thirteen water bodies, all of them referable to container categories (6, 7, 8, 11) were studied during my survey. In addition to the types of larval habitats named by Black, a large tree hole was noted. This, and an inland pool in a coral boulder, were the object of a special visit in the company of islanders who claimed them to be the only permanent natural fresh water sources on Bellona. Three of the five species of mosquitoes recorded, *Aedes albopictus*, *A.*

*aibolineatus* and *A. s. scutellaris*, are primarily container breeders. *Culex halifaxi* utilizes quite a wide range of larval habitats and was found elsewhere in large and small simple containers, while *C. fraudatrix* is primarily a surface water breeder (Perry, 1946; Bick, 1951) which nevertheless often breeds in natural and artificial containers as well (Belkin, 1945; Bick, 1951). This last species flourishes in the latter types of habitats in the absence of other breeding places on both Bellona and Renell.

*Anopheles farauti* almost always utilizes surface waters as larval habitats, as for that matter do all the Pacific anophelines. Thus, of the 58 collections in which *An. farauti* figured during these studies, only three were made from containers—a rock crevice on Espiritu Santo (coll. no. 36); a 14 gallon drum on Guadalcanal (coll. no. 276); and a halved coconut shell on Aore (coll. no. 13). The only mosquitoes which have succeeded in establishing themselves on Bellona are either primarily container breeders or else species which in other places readily utilize containers as larval habitats. It is thus considered that while occasional collections of *An. farauti* larvae might from time to time be found in container habitats at Bellona were sufficient surface water habitats available there for the maintenance of a heavy population of this mosquito, the lack of surface water precludes its establishment from taking place.

Tutuba, New Hebrides ( $15^{\circ}33'S$ ,  $167^{\circ}17'E$ ), is anopheline-free although only three kilometres away from Aore and the same distance from the southwest coast of Espiritu Santo, in both of which places *An. farauti* is abundant. This small island was visited during August, 1952, and as already described in detail (p. 58 ff.) it was found to lack surface water accumulations with the exception of duckweed-covered forest ponds. The low-lying coral platform of the northern part of Tutuba is so porous that transient pools are not formed during dry season showers, although it is possible that such pools may exist to a limited extent under wet season conditions. The permanent establishment of *Anopheles farauti* on the island is rendered most unlikely because of the thick covering of *Spirodela* on the only ponds which persist through the dry season.

Turning now to the southern perimeter of the malarious zone, anopheline-free Futuna lies about 65 kilometres from malarious Ameityum to the S.S.W. and from malarious Tanna to the west. Futuna, the most easterly island of the New Hebrides, is a Polynesian outlier and has long had the reputation of being a healthy island at the edge of a highly malarious zone. Steele (1880) stated that "some of the missionaries have called it 'the Madeira of the New Hebrides' and have advocated its claims as a sanatorium for those resident on the other islands," while Paton (1894) referred to it as seeming "so home-like and healthy, having no fever and ague."

Mills (1954) undertook a thorough malaria survey at Futuna during November, 1952, taking blood films from 286 of the 294 islanders. All of these preparations were negative for *Plasmodium*, and Mills also reported that the spleen index was nil. He noted the presence of seepages (often brackish) and small streams and felt that as there are permanent surface water sources there must be some ecological factor which makes Futuna an unsuitable location for *An. farauti*.

My wife and I visited Futuna from February 19 to 23, 1953, at the height of the wet season. We located and studied a total of 15 water bodies, only two of which did not contain mosquito larvae. Ten of these habitats were referable to container categories (6, 7, 11), while four transient pools and a ponded stream were located. It is probable that numerous stream-bed ponds are formed under dry season conditions. Three of the transient pools held developmental stages of primarily container-breeding mosquitoes, *Aedes s. scutellaris* (twice) and *Tripteroides melanisensis* (once). Two of these in addition contained larvae of *Aedes vexans nocturnus*, an exclusively surface-water breeder not previously recorded from the island. No larvae were present in the remaining transient pond or in the ponded stream (coll.

no. 16<sup>1</sup>), in which the combination of a lack of plant shelter and the presence of numerous predators including abundant dytiscid beetles (*Rantus annectens*) probably accounted for the absence of mosquitoes.

There were no unusual ecological factors associated with the four transient pools studied at Futuna, apart from the fact that the only one from which mosquitoes were absent (17<sup>1</sup>) contained such huge numbers of larval and pupal chironomids (*Tendipes* sp.) that competition for the available food must have been such as to operate against the successful establishment of the bottom-browsing larvae of *A. vexans nocturnus* (p. 89). With this one exception arthropods other than mosquitoes were absent, as indeed were any of the mosquito parasites and commensals recorded elsewhere. Fifteen (26 per cent.) of the 58 collections of *Anopheles farauti* from the New Hebrides, the Solomons and Queensland were made from transient pools, and there are no grounds for postulating that such pools on Futuna are unsuited to this mosquito. Mills (1951) was of the opinion that "we must assume that at various times the anopheline mosquito has reached Futuna," on the grounds that easterly upper air currents could easily sweep adult *An. farauti* to the island from Tanna and that adults and larvae could easily be introduced on board small ships and canoes. With regard to his wind-dispersal hypothesis, it may be of significance that *A. vexans nocturnus* occurs at Futuna, this species lending itself to distribution through the agency of air currents. *An. farauti*, however, has a very limited flight range and its habits are not such as to favour its distribution by upper winds. It has already been pointed out (p. 10) that inter-island shipping greatly favours the dispersal of the "domestic" non-anopheline mosquitoes over that of South Pacific anophelines, but for all that it is admittedly possible that introductions of *An. farauti* have taken place at Futuna by this means.

The arrival of a ship having adult *An. farauti* aboard at Futuna, however, might be repeated many times without the establishment of the species being achieved. First of all, the island has a cliffted coastline and any visiting vessels must lie well offshore at either of the two anchorages, Mission Bay or Herald Bay. All communication with the shore is by native outrigger across the fringing reef. While the flight from ship to shore would in itself present a hazard to anophelines, these would still have to make their way to the cliff tops before having any chance of locating suitable larval habitats—there are no coastal marshy areas such as exist on Aneityum, Espiritu Santo and other malarious islands of the New Hebrides. Such suitable breeding places as do exist are scattered about the relatively flat inhabited areas at altitudes of from approximately 30m to 60m, and the way to these is barred by forested country. Behind the villages the land rises steeply to a truncate peak 589m above sea level, the few small streams of the island arising on the flanks of the central hill. It is contended, therefore, that although suitable larval habitats await *Anopheles farauti* on Futuna, the mechanical obstacles barring the way to them, and their fewness in number, have thus far kept the island free from this mosquito despite the long-standing shipping contacts with nearby malarious islands.

The nearest anopheline-free islands to the west of the Southern New Hebrides are those of the Loyalty Group. It was only possible to visit one of these, Uvea, which is a large atoll (approx. 52km by 40km) positioned 166°25'E and 20°35'S some 325km west of Aneityum and 23°S of that island. A mosquito survey was undertaken at Uvea from March 21-21, 1953. Thanks to the kindly assistance of the gendarmerie stationed there, Lt. Blanchard, it was possible to make collections throughout the main islet from Lekin near the southern end to the brackish swamps near St. Joseph in the north. Fifteen separate collections were made, 10 of these—all from surface water habitats—including larval mosquitoes. The only species recorded was *Culex annulirostris*, three of the collections being made from freshwater ponds, three from brackish ponds and four from salt marshes. It was most surprising that *Aedes vigilax*, so common on the coasts of New Caledonia itself, was not found breeding in the brackish habitats near Lekin and St. Joseph.

It is hardly to be expected that the species does not occur there, especially as American wartime surveys revealed an 11 per cent. microfilaria rate (*Wuchereria bancrofti*) on Uvea (Perry, 1950) and *A. vigilax* has recently been claimed to be the vector of *W. bancrofti* in New Caledonia (Iyengar, 1954).

Three of the *C. annulirostris* collections on Uvea were made from category 1 habitats and three from category 9 habitats. Apart from the fact that one of the Uvea ponds (coll. no. 139) was recorded as having a temperature of 35°C, which is 5°C above the maximum recorded for category 1 habitats supporting both *C. annulirostris* and *An. farauti* and 3°C above the maximum noted elsewhere (coll. nos. 198, 200, Guadalcanal); for any breeding places of *An. farauti*, the physical and chemical characteristics of these ponds compare closely with those of habitats of the same categories supporting the last-named species as well as *C. annulirostris* in the malarious zone. Thus the following results are obtained from a comparison of the three Uvea category 1 habitats in question (coll. nos. 139, 140, 141) with the relevant ones from Queensland (coll. nos. 326, 336, 354, 363), the Solomons (coll. nos. 285, 290, Sikaiana) and the New Hebrides (coll. nos. 6, 103, 104, 105, Aneityum, and 17, Espiritu Santo).—

Factor	Queensland, Solomons, New Hebrides	Uvea
Nature of bottom	Mud in all cases	Mud in all cases
Foulness	27 per cent. positive	33 per cent. positive
Shade	55 per cent. positive	67 per cent. positive
Temperature factor	80 per cent. positive	67 per cent. positive
Temperature, °C	18 - - 30 (av., 23.5)	25 - - 35 (av., 29)
pH	6.2 - - 7.1 (av., 7.0)	7.0 - - 7.4 (av., 7.3)

The bulk of the macrofauna of the three Uvea ponds consisted of Hemiptera (Gerridae, Veliidae, Mesoveliidae, Notonectidae and Pleidae), a few freshwater snails, dytiscid beetles and larval damselflies and chironomids also being recorded. Most of the category 1 habitats in which both *An. farauti* and *C. annulirostris* were breeding featured an appreciably heavier predator population, the Hemiptera and Coleoptera being well represented and larval Plecoptera (*Caecidotea* sp.) and Odonata being of common occurrence.

The most striking biological difference between the two groups of ponds was in the matter of vegetation, those in the malarious zone supporting various phanerogams and their algal flora, where present, being chiefly composed of *Spirogyra*, while the vegetation of the Uvea ponds under consideration was largely made up of masses of *Oedogonium*, *Rhizoclonium* and *Chara*. In fact, with the exception of a species each of *Closterium* and *Vaucheria* and the brackish water *Spirogyra submersa* all the Chlorophyta recorded from Uvea were referable to halophilic genera of the Oedogoniales and Cladophorales (*Rhizoclonium*, *Pithophora*, *Spongomerpha*), while the bulk of the algal collections from brackish larval habitats of *C. annulirostris* there were made up of Cyanophyta.

From time to time suggestions have been put forward that certain algae are mimetic to mosquito breeding. Among the Chlorophyta *Chara* spp. and *Cladophora holsatica* Kütz have been named in this connection. Hamlyn-Harris (1928), having discovered the latter species in a cement-lined fountain at Brisbane, Queensland, found that although *Culex pipiens fatigans* will oviposit in laboratory containers in which the alga is present, the larvae which hatch out fail to reach maturity. Matheson and Hinman (1931) reported similar findings from laboratory experiments with *Chara* spp. and *Culex* spp. in the U.S.A., but Hamlyn-Harris (1932) demonstrated quite conclusively that charophytes are of no value in the biological

control of mosquitoes in Queensland although he admitted that mosquitoes are commonly lacking from natural waters containing these algae. Mosquito larvae were present in four of the five ponds from which charophytes were recorded during the present studies, *An. farauti* being collected from two of the habitats concerned in Queensland (coll. nos. 343, 360). The explanation proposed by Matheson and Hinman (1931) for the adverse effects on mosquito larval development which they associated with the presence of *Chara* was that the excessive amount of oxygen given off by the algae during photosynthetic activity brings about the death of larvae which ingest excessive amounts of tiny oxygen bubbles or which are hampered in their activities by these bubbles becoming entangled in their body hairs and mouth brushes. These authors conducted experiments which indicated that larvae of *Aedes stimulans* Walker and *Culex p. pipiens* L. die within three to five days in consequence of the continual passage of minute bubbles of oxygen through the water of their containers, and also showed that mosquitoes can complete their development in *Chara* cultures grown in the dark. Finally, Williamson (1935) stated that in Malaya, when *Oscillatoria* and related blue-green algae replace *Chlorophyta* in waters which become fouled, *Anopheles maculatus* Theobald disappears along with the green algae.

The formation of myriads of tiny oxygen bubbles is particularly characteristic of bottom felts of Cyanophyta, Cladophorales and Oedogoniales in shallow, mud-bottomed ponds exposed to bright sunlight. From time to time portions of the felted growth, buoyed up by the masses of oxygen bubbles, break away and rise to the surface. This phenomenon was noted on 16 occasions, six times at Uvea (coll. nos. 138, 140, 112-145), twice at Aneityum (coll. nos. 72, 114), twice at Aitutaki (coll. nos. 20<sup>1</sup>, 115), twice at Guadalcanal (coll. nos. 193, 199), once at Tarawa (coll. no. 57<sup>1</sup>), once at Funafuti (coll. no. 312) and twice in Queensland (coll. nos. 331, 334). Mosquito larvae were collected from 13 of the water bodies concerned, *Culex annulirostris* being present in no less than 11 instances. *Anopheles farauti* was never found in such habitats, although the closely related *An. punctulatus* was recorded from the two highly oxygenated breeding places on Guadalcanal.

These findings indicate that while some mosquitoes, such as the American *Aedes stimulans* and *Culex p. pipiens*, are inhibited in their development by excessive oxygenation of the water, other species, such as the Pacific *C. annulirostris*, tolerate the condition very well. It may be that we have here the explanation of why larval *An. punctulatus*, which also appears undeterred by excessive oxygenation, utilizes exposed transient pools as breeding places much more commonly than does *An. farauti* (Lee and Woodhill, 1911; Belkin et al., 1945; Laird, 1946a; Horsfall and Porter, 1946; Bick, 1951); for pools of this type are often dominated by Cyanophyta (Smith, 1950).

The presence of Cyanophyta, Cladophorales and Oedogoniales does not in itself preclude the larval development of *An. farauti* in waters containing these algae. All stages of this mosquito were abundant in a pond at Sikaiana (coll. no. 285) in which all the algae were referable to the Cyanophyta, and were present in five other larval habitats supporting Cyanophyta, Cladophorales or Oedogoniales (coll. nos. 250, 267, 277, 328 and 339). The formation of oxygen bubbles was not, however, noted in any of these habitats. It is pertinent in this connection that during a mosquito survey of Nissan Island (an atoll located between the northern Solomons and the Bismarck Archipelago) in 1915, larval *An. farauti* were collected from 16 semipermanent ponds (category 1) having marginal and emergent vegetation and floating masses of mixed green and blue-green algae (*Spirogyra*, *Hormidium*, *Oscillatoria* and *Anabaena*) but were absent from two pools having no vegetation other than felted bottom-dwelling algae (Laird, 1952). On looking up the relevant field notes I find that the two latter pools contained only *Oscillatoria* and

*Anabaena*, the felts of which were noted as being heavily oxygenated. No similar note was made in respect of any of the other 16 water bodies.

Thus, although the category 1 and 9 larval habitats studied at Uvea seem suited to the larval requirements of *An. farauti* on physical and chemical grounds, and their utilization by fewer predators than typically occur in comparable water bodies in Queensland, the Solomons and the New Hebrides would appear to favour the establishment of this mosquito were it ever introduced into the atoll; the fact that the algal flora is largely composed of felt-forming species which bring about excessive oxygenation of the water in the presence of sunlight may well be acting as an ecological barrier against such an introduction.

The northern tip of New Caledonia and the off-lying island of Baaba lie in the same latitude as Aneityum, which is some 580 km to the east. The 37-kilometre long chain of the Belep Group, the raised islands of which represent an extension of the mainland ridge, commences about 18 km to the north-west of New Caledonia itself. Buxton (1926) indicated that the Belep Islands represent an anopheline-free intrusion into the malarious zone of Melanesia, and the results of the most recent investigations there indicate that *Anopheles* is still absent as it is from the Loyalty Group and New Caledonia (Laird, 1951a).

Art, the largest of the Belep Islands reaches an altitude of 222 m and has a wider variety of mosquito larval habitats than has Uvea. While only *Culex annulirostris* was recorded from Uvea, *Tripteroides melanoeensis*, *Aedes vigilax* (adults only), *A. vexans nocturnus*, *Culex annulirostris*, *C. pipiens fatigans*, and *C. fraudatrix* were all collected at Art during an eight-day visit in December, 1952. *C. annulirostris* was represented in five of the larval habitats studied, one of these being a permanent pond (coll. no. 48), two being transient pools (coll. nos. 47, 54), and two being brackish ponds kept filled by seepage (coll. nos. 52, 53). Larvae of this species were also noted in ponded ditches at Uala, but as the tubes containing the relevant collections were broken en transit these records are disregarded herein. None of the water bodies examined held *Cyanophyta* or any other filamentous algae.

Two of the *C. annulirostris* breeding places were in exposed positions. Their water temperatures were 38°C (coll. no. 53) and 39°C (coll. no. 54), while the highest reading for any larval habitat of *Anopheles farauti* was 32°C (coll. nos. 198, 200, Gaudalcanal). The remaining three breeding places were closely comparable with actual *An. farauti* larval habitats. Collection number 47, for example, was made from a transient pool very similar indeed to one studied at Espiritu Santo (coll. no. 30) which supported *An. farauti* as well as *C. annulirostris*. The water in both pools was turbid and foul, pigs having access to it in both cases. A bottom covering of dead leaves and a slight degree of shade from nearby vegetation were further factors the pools held in common, while the temperature and hydrogen ion content of the Art pool were 27°C and pH 7.0 and those of the New Hebridean one were 25°C and pH 7.4. Larvae of *C. annulirostris* were abundant and infested with *Vorticella microstoma* and *Epistylis lacustris* in both collections. Neither pool held algae or had emergent vegetation, and the only arthropods other than mosquitoes present were larval *Tendipes* (both pools) and a few small dyiscids (*Bidessus cheesmanae*) (at Art only).

The comparison between one of the brackish ponds at Art (coll. no. 52) and one at Aneityum (coll. no. 94) is also close. Both ponds were mud-bottomed and shaded by nearby trees, and their water was turbid and fouled by pigs. The temperature and hydrogen ion content recorded for the Art pond were 24°C and pH 7.4, while those for the Aneityum one were 23°C and pH 7.2. In both cases there was a 10/10 cover of floating pumice. Both ponds supported no vegetation whatever, and their faunal index was the same (2), the arthropods present including larval Zygoptera and Dytiscidae in each case. Once again there was no reason to suppose that the Art pond could not serve as a larval habitat of *An. farauti* as-

readily as the one at Aancyum in which larvae of this species were present in addition to those of *C. annulirostris*.

The evidence suggests, therefore, that suitable larval habitats await *Anopheles farauti* at Art. As to whether the conditions there would suit adults of this species is, however, another matter. All the malarious islands visited, Bellona, Tumua, Futuna, Uvea and the various Polynesian groups, support tropical rain forest having a lush undergrowth. The geological structure of Art stands apart from all of these other localities. The island is largely of serpentinite formation, and its southern and western portions are characterized by arid, ochreous-red soil which supports a sparse, drought-resistant scrub (Laird, 1954a). This flora, which has very much the appearance of New Zealand subalpine scrub, altogether lacks the lush undergrowth which is present elsewhere in the islands surveyed. The eucalypt or niaouli forest (*Macaranga leucoxylon*), stretches of which occur over the central spine of Art, is likewise devoid of moist undergrowth. The only typical tropical jungle occurs on the coastal strip at the foot of the northeastern cliffs, where three of my collections (coll. nos. 32-51) were made.

Roberts (1918) pointed out that rain forest apparently indicates the existence of the appropriate conditions of humidity, temperature and shelter necessary for the establishment of *An. farauti*, while Roberts and O'Sullivan (1949) showed that in Queensland and New Guinea adults of this mosquito usually rest during the day in moist, sheltered spots close to the ground in bush country. Such observations as have been made in the New Hebrides and Solomons are in agreement with this, Belkin et al. (1945) including among the diurnal resting places which came to their notice buttressed tree trunks, grass, the shaded, moist earthen walls of pits and holes, and moist situations beneath felled logs. Only rare resting places of this nature would be available to *An. farauti* on so arid an island as Art, where the most favourable area for the establishment of the species is on the opposite side of the island to Uala, the settlement and landing place on the western coast. For these reasons, despite the occurrence of suitable *An. farauti* larval habitats at Art, it is considered that there is a formidable ecological barrier to the establishment of this insect there.

A similar case may be made out for the northern parts of New Caledonia itself, which are generally arid and clothed by sparse scrub and niaouli forest. Although a wide range of larval habitats apparently suited to *An. farauti* occur there, the paucity of suitable adult diurnal resting places is as obvious as at Art. Perry (1950) drew attention to the theory, widely held by many people in New Caledonia, that the absence of *Anopheles* from their country is ascribable to a repellent effect exercised by the bark and leaves of the niaouli trees which so often dominate the landscape. Such ideas associated with eucalypts have had wide currency. Howard et al. (1912) reviewed the subject, recalling that a Californian correspondent of the Bureau of Entomology, U.S. Department of Agriculture, had claimed that although an irrigation ditch ran through a grove of *Eucalyptus* about his house, mosquitoes never bred there although larvae were plentiful on both sides of the plantation. These authors concluded that the idea that eucalypts preclude mosquito breeding must be abandoned, pointing out that in California Culicidae are often most numerous where these trees are most abundant and quoting Sergeant for the information that an Algerian railway station, formerly greatly troubled by mosquitoes, was visited much less frequently by these insects after surrounding *Eucalyptus* trees had been felled. The theory as held in New Caledonia has particular reference to anophelins, not to mosquitoes in general, and of course merely draws attention to the two most striking biological features of the island as compared with the nearby New Hebrides, the absence of *Anopheles* and the dominance of eucalypts, and claims the first of these features to be a consequence of the second. Nevertheless, it is contended that although entomological evaluation of the claims that eucalyptus trees exercise a repellent effect against *Anopheles* have failed to corroborate this (Perry, 1950), the presence of sparse forests of

*Melaleuca leucadendron* is indicative of conditions of low humidity unfavourable to the requirements of adult *An. farauti*. This mosquito might perhaps have its best chance of gaining a foothold in New Caledonia in the wet bush of the eastern side of the island. The opportunity of visiting this area did not present itself during these studies. It is felt that the chances of accidental introductions of *An. farauti* taking place are much higher as regards the drier western coast, for although small ships trade between east coast ports and the Loyalties, overseas traffic is virtually confined to the west coast ports of Noumea and Koumac and the airport of Tontouta north of Noumea.

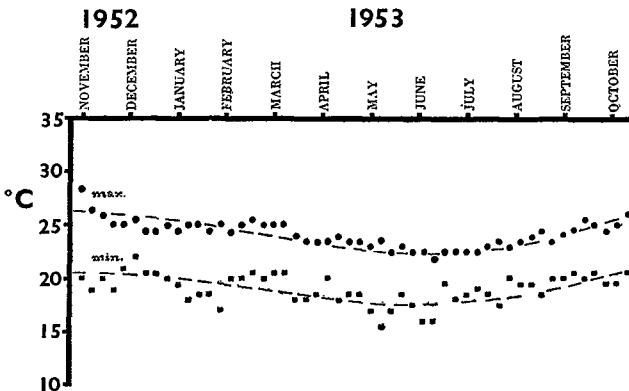
The distribution of *An. farauti* in Queensland supports these conclusions concerning New Caledonia. Thus at Kuranda on the Atherton Tableland behind Cairns large stands of rain forest occur, and Roberts (1948) found larvae of this species to be plentiful there. This author, however, found very few larvae in the country between Kuranda and Mareeba which is dominated by scattered eucalypts. He likewise indicated that while *An. farauti* is very common on the Queensland coastal plain between Daintree and Innisfail, larvae are hard to find south of the latter town and do not occur at all south of Ingham where there are only small and isolated stands of rain forest at low altitudes and "the extensive areas of dry, open eucalypt forest would be unsuitable as shelter for adults." The comparatively few collections made in these areas during June, 1954, are in accord with Roberts' observations. Larvae of *An. farauti* featured in nine of the 21 larval collections made in the coastal areas in the vicinity of Cairns, where rain forest, mangroves or heavy undergrowth were always to hand affording suitable diurnal resting places for adults. The species was represented in only one of the nine Atherton Tableland collections (coll. nos. 350-358), this one being made at Kuranda. It was present in four of the eight collections from the coastal plains between Babinda and Ingham, and was also found in the shelter of vegetation at the edge of a flowing stream five miles south of Ingham (coll. no. 367). All five larval collections made between here and the Townsville area were from eucalypt country, and *An. farauti* was absent from all of them.

Temperature is a further factor which must be taken into consideration in assessing the distribution of *An. farauti* in Queensland and also in the southern Pacific islands. The nature of these studies did not permit of year-round adult catches for correlation with air temperature and humidity nor could laboratory experiments on the temperature range tolerated by developmental and adult *An. farauti* be undertaken. As already noticed (p. 186) larvae were never collected from water at temperatures above 32°C, but the fact that Buxton (Buxton and Hopkins, 1927) recorded the species (*An. punctulatus*) from a hot spring (c.38°C) at Tamai, New Hebrides, indicates that the upper limit of tolerance is considerably higher than my own field observations suggest.

It is the lower end of the tolerable temperature range which is most pertinent to the distributional problems under consideration. Roberts (1948) stated that although there are large stands of rain forest on the higher parts of the Atherton Tableland, which rises to an altitude of approximately 915m, *An. farauti* was not collected there during his survey or in the course of various wartime surveys by mosquito control units. He considered that the relatively low temperatures of the area are probably inimical to the successful establishment of *An. farauti*, despite the presence of otherwise suitable larval habitats and diurnal resting places for adults. At Ingham, which is very close to the southerly limit of *An. farauti* in Australia, the annual mean minimum air temperature (20.5°C) corresponds with that of Aneityum, where the relevant figures for 1919 and 1951 were 20.5°C and 20°C. It was felt that a year's water temperature records from an anopheline larval habitat on the coast of the latter island would be of value in furnishing a picture of the lowest temperature conditions to which the developmental stages of *An. farauti* are subjected in a lowland Pacific territory.

Through the kind co-operation of the S.P.A.T.C. at Vila, New Hebrides, a year's maximum and minimum water temperature readings were taken at a taro pond near Aneigauhat, Aneityum (coll. no. 6). The pond in question, a permanent one, is located at the southern extremity of the island and is probably the most southerly permanent larval habitat of *An. farauti* in the South Pacific. A small thatched shelter was built in the pond, and beneath this was moored a rubber tyre to which a maximum/minimum thermometer was attached in such a manner that its bulb was fully submerged. Readings were taken at 5 p.m. daily from November, 1952, to November, 1953, by a member of the New Hebridean meteorological staff stationed at Aneityum. The weekly averages are given in Text-fig. 3, the maximal and minimal means for the year being 24.5°C and 19°C respectively and the mean daily range thus 5.5°C. During the second visit to the island (February-March, 1953) the meteorological assistants were trained to dip for mosquito larvae and to differentiate between larval *Culex* and *Anopheles*. From then onwards until the records ceased in November of that year a note was made each day as to whether or not anopheline larvae were found in 20 dips made with a 210 cc. ladle amongst emergent vegetation alongside the recording station. All the routine samples made during the two wettest and hottest months of the period in question, February and March, proved positive for *An. farauti*. The maximum and minimum water temperatures for these months averaged 25.5°C and 20°C respectively, and the minimum reading never fell below 17.5°C. During the following six months of the dry and cool season the average water temperatures were as shown in Text-fig. 4. Anopheline larvae were not recorded on seven days in April, 14 in May, 19 in June, 24 in July, 22 in August and 19 in September. The water temperature never fell below 17.5°C on any of the 78 days on which larvae were collected during these six months, while on 52 (50 per cent.) of the 105 days on which no larvae were noted temperatures below this level were recorded.

Of course, each day's larval sampling being confined to an arbitrary 20 dips in one part of the habitat only, the results cannot be interpreted as indicating that



TEXT-FIG. 3.—Maximum and minimum water temperatures from an Aneityumese taro pond (coll. no. 6), 1952-53. Weekly averages plotted.

breeding was actually suspended in any given period. The figures do, however, suggest that a minimum water temperature of 17.5°C is close to the lower limit tolerated by *An. farauti*, for larvae were never collected on days when readings fell below this level although they frequently figured in the samples made immediately preceding and following such days. They were thus obviously present on some at least of the coldest days, but were probably overlooked because they had temporarily concentrated in areas of the pond warmer than the shaded one where dipping was always done.

Incomplete and sketchy though these field results are, they serve to indicate the desirability of a careful laboratory investigation of the temperature tolerances of *An. farauti*. The question is of particular relevance to the possibility of the establishment of the species in New Caledonia, where although the annual mean minimum air temperature at Koumac (19°C) is appreciably less than at either Ingham or Aneityum, the figure for Noumea (20.5°C) is equivalent to the readings for the latter two places.

Turning now to Fiji and the various other anopheline-free groups to the east of the New Hebrides, we find that there are a multitude of islands which not only support similar jungle and rain forest to the islands of the New Hebrides and Solomons, and thus afford conditions suited to the adults of *An. farauti*, but also have warmer climates than do the southern islands of the former group. The possibility of the lower limit of the adult and larval temperature tolerance of *An. farauti* being reached does not arise in such islands as Viti Levu, Upolu or Aitutaki where the annual mean minimum air temperatures are 21.5°C (Suva), 23.5°C (Apia) and 22°C respectively.

In the case of the large permanent ponds of Category 1, close comparisons may be drawn between examples from the malarious and anopheline-free zones. Thus the ponds in a coral borrow pit in Espiritu Santo (coll. no. 17) and in another such pit at Aitutaki (coll. no. 116) were superficially similar to one another. In both cases the bottom consisted of coral sand and mud and a degree of shade was provided by sedges and water lilies. Cattle had access to the two ponds, the water being slightly turbid and rather foul. Small masses of *Spirogyra* were present in both ponds, and the faunal index was three in each case. Predaceous insects were in evidence in both habitats, larval damselflies and dragonflies being common to them and species of *Microvelia*, *Plea* (Hemiptera) and *Enochrus* (Coleoptera) occurring at Espiritu Santo only. *Anopheles farauti* was recorded from habitat number 17, where its larvae were associated with those of *Culex annulirostris*, the only mosquito breeding in the Aitutaki pond. The *C. annulirostris* larvae from both habitats were infested with *Vorticella microstoma*. The hydrogen ion content (pH 8.0) and temperature (30°C) of the Aitutaki pond were both within the range of tolerance of *An. farauti* larvae, and the less complex fauna there could not but favour this mosquito were it ever introduced from the west. Other permanent larval habitats of the types utilized by *An. farauti* are available in plenty at Aitutaki, notably taro irrigation areas comparable with those at Sikaiana and Aneityum but supporting much less complex predator populations than are found in the western islands of the Pacific.

A comparison between a taro pond at Aneityum (coll. no. 104) supporting both *An. farauti* and *C. annulirostris* and another at Tarawa (coll. no. 309) supporting the latter species only may be made with advantage. The water in both ponds was clean and clear, marginal shade being provided by taro plants (and sedges, in the case of the Aneityum habitat). The hydrogen ion content was pH 7.1 in both cases, and the temperature of the pond at Tarawa (31°C) was within the range of tolerance of *An. farauti* larvae. Both ponds were shallow and mud-bottomed. No filamentous algae were present in either case. The faunal index of the New Hebridean pond was 4 and that of the one at Tarawa only 2, the former habitat

supporting numerous predators including species of *Caridina* (Decapoda), *Enithares* (Hemiptera), *Hyphydrus* and *Enochrus* (Coleoptera) as well as larval Odonata which were the only mosquito larval enemies present in the Tarawa pond. A similar case could be made out for the suitability of Fijian and Samoan taro ponds for *Anopheles farauti* (e.g. coll. no. 170, Upolu), attention having already been drawn to this point as regards Suva and Apia (Buxton and Hopkins, 1927).

Two of the transient pools studied, one of them (coll. no. 30) a larval habitat of *An. farauti* and *C. annulirostris* at Espiritu Santo and the other (coll. no. 172) supporting the latter species and also *C. pipiens fatigans* at Apia, Samoa, likewise proved comparable in most respects. Both of them were on muddy ground and had a bottom covering of dead leaves. The water was very turbid and foul, pigs having access to both pools. In each case the surface was partly shaded and the hydrogen ion content of the water was pH 7.1. The *C. annulirostris* larvae in both pools were infested with *Vorticella microstoma* and *Epistyliis lacustris*. No aquatic vegetation was present in either case. The phytoflagellates *Phacus pleuronectes* and *Trachelomonas hispida* were common to the two pools, as were the ostracod *Stenocypris malcolmsoni* and cladocerans of the genus *Moina*. No predators other than small water-striding hemipterans, *Micropsectra* sp. (coll. no. 30) and *Mesovelia* sp. (coll. no. 172) were present. The only faunal differences observed were the presence of large numbers of notifiers in the New Hebridean pool and their absence from the Samoan one, and the occurrence of abundant annelids (*Aulophorus* sp.) in the latter habitat but not in the former one.

These comparisons suffice as evidence that suitable larval habitats in plenty await *Anopheles farauti* east of Buxton's Line (170°E.). The breeding requirements of this species are very close to those of *Culex annulirostris*, as is indicated by a comparison of averages derived from the physical data concerning the larval habitats of these two mosquitoes in Table I.

<i>Factor</i>	<i>An. farauti</i>	<i>C. annulirostris</i>
Nature of bottom:		
Bare	5%	4%
Leaves	16%	13%
Mud	76%	79%
Stones	3%	4%
Foulness of water	43% +	50% -
Temperature factor	89% +	83% +
Available shade	62% +	61% +
Available shelter	62% +	69% -

Larvae of *An. farauti* and *C. annulirostris* were found in association in 34 collections from Aneityum, Aore, Espiritu Santo, Renell, Guadalcanal and Queensland, these collections accounting for 59 per cent. of the total of 58 for the former species and for 57 per cent. of the 60 relevant ones for the latter species.

It is considered that those breeding places of *C. annulirostris* in the anopheline-free islands in which the water temperature remains within the usual tolerance of *An. farauti* larvae (from field observations approx. 17.5°C.—32°C.) and in which the algal flora is not dominated by oxygenated felts of *Cyanophyta*, should be regarded as potentially suited to the development of the latter mosquito, the types of breeding places chiefly concerned being permanent ponds, marshes, transient pools, ponded streams and brackish ponds, in each of which these two species hold the first two places in my overall survey results. The collections to which the following numbers refer were made from *C. annulirostris* larval habitats which not only appeared to meet all the larval requirements of *An. farauti* but which were adjacent to heavy undergrowth suitable as diurnal resting places for the adults of this anopheline.—Viti Levu.—38, 39, 119, 298, 299, 301, 302. Tongatapu.—292, 294. Upolu.—171, 176, 182. Aitutaki.—118, 119, 121, 122, 124. Tarawa.—301, 303, 307. Funafuti.—312.

## CONCLUSIONS

It was the aim of this project to make general aquatic collections from as many localities as possible, employing standard techniques so that conclusions might be drawn having particular application to the ecology and distribution of a single insect family, the Culicidae. An account of the aquatic flora and fauna of the South Pacific having any pretensions to completeness was never contemplated. Not only would such a task have been of too great a magnitude to fit the time available, but in any case it could not be concluded satisfactorily because much of the material that has been collected in the past is still awaiting attention in museums. Previous records are, of course, drawn upon in sketching the distributional pattern of each of the groups concerned, with particular reference to islands which it was not possible to visit. Otherwise, the present conclusions—in which a large measure of speculation is naturally unavoidable—are based entirely upon the data gathered during these surveys.

Nevertheless, these data are sufficiently comprehensive to indicate the broad trends of aquatic biogeography in the region. Climatic conditions at sea level do not vary greatly from Cairns eastwards to Aitutaki and beyond, but the findings confirm those of earlier investigators who observed that in group after group of plants and animals representation decreases as longitudinal distance eastwards increases. It is true that this trend is much less marked in the case of the less specialized organisms. Thus the Algae and Protozoa of Pacific ponds are referable to cosmopolitan species, and individual species such as the phytoflagellates *Phacus flevonectes* and *Trachelomonas hispida* are to be found wherever a search is made for them. In the Rotatoria, too, only one undescribed species was taken; the other collections merely served to extend the known range of familiar and widespread forms. Numerous cosmopolitan and pantropical Entomostriata were similarly found, although endemism is more apparent in this group, particularly in the Ostracoda. Wind transportation of spores, cysts and other resting bodies minimizes the significance of ocean barriers to the organisms mentioned thus far. These barriers hardly exist for some of the higher plants and animals also, for example the sedges *Cyperus haspan* and *Eleocharis geniculata* which have attained a pantropical distribution by natural means, and strong-flying or soaring insects including the dragonflies *Pantala flavescens* and *Diplacodes bipunctata* and the damselfly *Ischnura a. aurora*. Certain of the larger and more powerful water beetles, including the dytiscids *Hydaticus consanguineus*, which was collected from Queensland to Samoa, and *Cybister tripunctatus*, which ranges from Indo-Malaysia to Samoa and has even reached parts of Micronesia (Balfour-Browne, 1915), belong here also.

To go to the other extreme, some of the organisms utilising freshwater habitats, the bivalve molluscs and amphibians for instance, are quite unadapted to trans-oceanic dispersal through natural agencies. Former land connections with the west must certainly be invoked to explain the occurrence of endemic freshwater bivalves in the Solomons and frogs in Fiji, and it is likely that such bridges also account for the presence of freshwater sponges in the latter group. There is geological and biological evidence for the former existence of emergent land linking western Melanesia not only with the continental islands of Fiji but also with Tonga and very possibly with Samoa too. It will be recalled in this connection that the presence of closely related mayflies of the genus *Cloeon* from Indonesia and Australia to the Philippines and Samoa has been cited as evidence of the former wide distribution of these weakly flying insects on an ancient Pacific land mass. Further support for this contention is to be had from the distribution of certain other insects the adults of which are not strong fliers while the larvae are aquatic, for example the Trichoptera, this family being represented in Fiji and attaining its most easterly limit in Samoa, and such mosquitoes as *Uranotaenia*, two species of which are endemic to Fiji, and *Tripteroides*, which is found as far eastwards

as Rotuma and Fiji. Reference has been made to the opinion of some authorities that the presence of decapods of the family Atyidae on oceanic islands is only to be explained by postulating one-time land connections, although as has been indicated this view is open to criticism.

In between these two extremes there are many freshwater organisms which, although not confirmed wanderers, are able to take advantage of natural means of dispersal upon occasion, while others are particularly well suited to make use of human agency in extending their range. The first group includes numerous insects which, although spending most of their life in or on water, can fly quite strongly when occasion demands. Here belong many of the Hemiptera and the smaller Coleoptera. To instance only the first of these orders the families Naucoridae and Nepidae are unknown east of Queensland, the Belostomatidae drop out in New Caledonia, *Rhagovelia* does not occur south or east of the Solomons, the Hydrophilidae and Corixidae reach their eastern limit in the Loyalties, the Pleidae are not known to extend east of the New Hebrides and the Mesovelidae are represented as far eastwards as Samoa; while of the three families ranging to the Society Islands two, the Gerridae and Notonectidae, are notable for their powers of flight, and the species of *Mirrovelia* (Velidae) are minute and probably lend themselves to transportation by the agency of man. Plants referable to this group would include halophilic grasses and sedges the seeds of which might conceivably be carried across the ocean by shore birds. In the second group we must place those insects closely associated with the kinds of containers in which water is either accidentally (e.g., rubber tyres) or intentionally (e.g., casks) taken on inter-island journeys, for example the "domestic" mosquitoes and chironomid midges of the genus *Culex*; organisms including small oligochaetes, helcid midges such as *Forcipomyia*, and plants of the family Lemnaceae which may be carried about with aquatic phanerogams valued as food or for their ornamental appearance; and, of course, those insects which stow away as adults aboard aircraft. Representatives of both the groups of organisms considered herein have shared the colonization of the water bodies of such strictly oceanic islands as Aitutaki and the atolls with the habitually wide-ranging plants and animals, and have contributed to the augmentation of the fauna and flora of the high islands since these attained their present isolation.

Just as the successive oceanic barriers encountered moving out across the tropical South Pacific away from the centres of distribution to westward each marks a further diminution of the aquatic fauna and flora, similar consequences result from the interposition of relatively minor sea gaps between high islands and adjacent low islands (e.g., New Caledonia and Uvea) and between high islands of individual groups. Thus there is a southward decrease from 18 species of mosquitoes on Espiritu Santo to nine (at least insofar as is known) at Aneityum, the southernmost island of the New Hebrides chain, although the latter island offers the whole range of larval habitats available on the former one. Of course the non-occurrence of certain aquatic organisms in particular regions or islands is sometimes to be explained on ecological grounds rather than by reasons of isolation. Cases in point are the prevalence of halophilic algae in atoll ponds, the paucity of desmids on coral islands where the surface waters are too hard for all but a few of these acidophilic algae, and the absence of *Anopheles farauti* from Tutuba because of a lack of suitable larval habitats.

Except as otherwise noted for specific islands such as Ait with its lack of lush undergrowth and the smaller atolls with their limited range of actual and potential mosquito larval habitats, coastal ecological conditions for aquatic organisms do not vary greatly from Queensland to central and eastern Polynesia. Most of this region, and most of the territories visited during these surveys, lie between the equator and 20°S latitude, and longitudinal distance from west to east is the most important single factor limiting plant and animal distribution. The fauna

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continuing development of the economic life of Fiji and of the major island groups of tropical Polynesia, and the inevitable growth of speedier and more frequent transportation links with the outside world, an unceasing vigilance to guard against accidental introductions of anophelines through human agency is the price that must be paid if these territories are to remain free from the threat of malaria.

The second conclusion to be drawn from the data submitted herein is that—at least until mosquito control is enforced far more satisfactorily in the region than at present—nothing should be done that will serve to increase the numbers of larval habitats or else render ones already existing more suited to mosquito breeding than they are to-day. Such mosquito predators and competitors as now occur in the central and easterly islands of the South Pacific succeed in keeping a partial check on mosquito breeding both by virtue of their abundance in individuals and the lack of sheltering vegetation. It cannot be too strongly emphasized that future introductions of aquatic plants into these islands should not be contemplated without the most mature examination of the possible consequences—rises in mosquito populations through the multiplication of places affording larvae shelter from biological control agents already present, the enhancement of the chances of successful establishments of introduced anophelines, and the partial if not complete negation of any future plans for biological control using exotic predators. It is urged that the South Pacific Commission authorities, in their laudable desire to supplement human vegetable food and pig fodder in the region by introducing the aquatic Sweet Potato *Ipomoea aquatica* Forsk. from South East Asia (Barraud, 1955), are unwittingly laying the foundations for greatly increased mosquito hazards in the islands they are endeavouring to assist. A further S.P.C. project, the encouragement of the pond culture of the food fish *Tilapia mossambica* Peters in their area of operation (van Pel, 1955, 1955a), is also fraught with risk. Anyone who has had personal experience of the anopheline and culicine control problems posed by the domestic fish ponds and hyacinth ponds of South East Asia must view these developments with grave concern. While it is true that if fish ponds are maintained in a vegetation-free state, any predators present, including the fish themselves, will keep mosquito breeding down to a minimum, in actual practice various aquatic plants including *Ipomoea* and Water Hyacinth are frequently cultivated for use as fodder or else are allowed to grow unchecked. It has already been suggested that *Tilapia* and *Ipomoea* should be cultivated in the same South Pacific ponds in order to increase the ultimate yield of these (Barraud, 1955). If this should be allowed to happen the resultant high intersection values (see pp. 57, 58) will favour mosquito breeding, and the wholesale creation of large numbers of additional permanent ponds in the scuttled areas of New Caledonia, Fiji and the Cook Islands, the islands initially concerned (van Pel, 1955), will both increase local mosquito populations and render the larval environment still more suitable for anophelines. Van Pel (1955) emphasized that *Tilapia mossambica* flourishes in brackish ponds as well as freshwater ones. Brackish fish ponds and prawn ponds in Malaysia often become choked with algae of the genus *Enteromorpha*, and *Anopheles sundaiacus* (Rodewaldt), perhaps the most dangerous malaria vector of South East Asia, then breeds unchecked. A warning has already been given that the salt marshes of New Caledonia might prove open to invasion by *An. sundaiacus* brought in from the north by aircraft (Laird, 1954a), and it is surely most undesirable that anything should be done to create still better breeding conditions for this mosquito.

Finally, the matter of the control of dangerous mosquitoes already present in various parts of the South Pacific must be considered. Experience during World War II proved that even so ubiquitous a species as *An. farauti* can be brought under control by employing modern insecticidal techniques on the grand scale. Full control, with the complete cessation of malaria transmission, was achieved in certain localities, notably those parts of Guadalcanal and Espiritu Santo where large numbers of troops were stationed. The necessary measures are, however, highly

and flora of larval habitats become less and less complex as one moves eastwards, the resultant deficiencies being most strongly marked in the higher groups of the aquatic animals and plants and least evident in the Algae, Protozoa and other small organisms. Thus, as increasing isolation renders freshwater habitats less and less fully utilized by all but the lowlier aquatic organisms, we notice more and more unoccupied niches ready to cater to all the requirements of a variety of as-yet absent plants and animals. Highly significant conclusions regarding mosquito distribution and ecology depend upon this biogeographic situation.

The first of these conclusions concerns the distribution of anophelines. It is obvious that Buxton's Line, instead of denoting a boundary between two major zoogeographical regions as does Wallace's Line, merely records one particular phase in the progressive reduction of a regional flora and fauna under the influence of increasing longitudinal distance from west to east. It indicates the eastward limits so far attained by the anophelines; similar "lines" could with equal justification be ruled further and further to the east to fit the facts of distribution of other mosquitoes or for that matter of a variety of animals from mayflies to amphibians, or to mark the easternmost locality Samoa—where mosquitoes utilizing *Pandanus* and *Coldiasia* leaf axils occur. As has been shown, the larval habitats of *Anopheles farauti* fall within the range of those of *Culex annulirostris*, which, through its ability to avail itself of human transportation, is now established throughout Polynesia. However, the latter species exhibits rather more catholic habits, its larvae tolerating somewhat higher water temperatures than do those of *An. farauti*, being found more frequently in large simple containers and being unaffected by the presence of oxygenated felts of blue-green algae which appear inhibitory to this anopheline. Accepting these observations, it is contended that the presence of *C. annulirostris* in the anopheline-free islands of the region is generally indicative of the presence of larval habitats that would suit *An. farauti*. Plausible ecological arguments may be invoked to explain the continued absence of this mosquito from islands within or near the malaria perimeter such as Tutuba, Ait and Uvea, and a simple lack of potential larval habitats protects Bellona and many of the small atolls. Climatic considerations together with other ecological factors weigh against the further southward dispersal of *An. farauti* in Queensland, and it is possible that New Caledonia lies a little too far to the south to favour the general establishment of the species; although this mosquito might be able to establish itself in certain areas, particularly in the wet bush on the eastern coast of the island. New Zealand is almost certainly too far south to be in any danger, although it is not unlikely that less dangerous anophelines which thrive under temperate conditions—the Australian *An. annulipes*, for example—could become established in the warmer parts of the country. The important consideration for the area covered by the present investigations is that it cannot be claimed that any general factor other than isolation is operating to prevent the extension of the range of *An. farauti* to those tropical islands east of Buxton's Line where the requisite ecological conditions present themselves. This line should not be regarded as indicative of a barrier beyond which anophelines are destined never to advance, but rather as an ever-present reminder of the proximity of a dangerous species of *Anopheles* to a zone in which it would flourish; for following its introduction into such groups as Fiji, Samoa and the Cook Islands *An. farauti* would not be subject to the attacks of any parasites to which it is not already exposed in its present area of distribution and would furthermore be favoured by a generally lower degree of competition and a higher degree of freedom from predators consequent upon the decreasing utilization of larval habitats by aquatic animals.

Once so formidable a vector of *Plasmodium* became established in the existing malaria-free zone of the South Pacific, opportunities for becoming infected from gamete carriers, such as Fijian troops who have contracted malaria on service in Malaya, would sooner or later arise. Primary epidemics might then be initiated, with devastating consequences. It is therefore considered that in the face of the

expensive; and they must be kept in force continuously. Thus only two months after the withdrawal of troops from Nissan Island, Territory of New Guinea, and the cessation of D.D.T. larvicide which had been enforced for some 18 months during 1944-45, Laird (1952) found extremely heavy concentrations of *An. farauti* larvae in all kinds of surface waters throughout the former control areas. Very few predators were in evidence even in the more permanent ponds. They as well as the mosquitoes had been affected by larviciding. They were taking materially longer to re-invade the area from foci outside the old control perimeter, and in the meantime the mosquitoes, with their much briefer life history, were developing unchecked. More recently a much more serious consequence of the continued use of chemical control agents, the development of resistance to residual insecticides, has become apparent in many parts of the world. Fears are already being expressed in some quarters that acquired resistance to the newer insecticides on the part of mosquitoes may very adversely affect current and contemplated regional control programmes.

Adequate mosquito control campaigns based on the use of larvicides and residual chemical sprays are, in any case, extremely expensive and beyond the purse of the less developed Pacific territories. It is true that filariasis control through anti-mosquito measures has made real headway in some areas, notably in the more developed islands of Viti Levu, Rarotonga and Tahiti (Beye, 1953), and that efforts are being made to apply residual spraying techniques to anopheline control in New Guinea (Black, 1955). On the other hand, anopheline control in the areas of European settlement in the Solomons and New Hebrides has slipped back badly since 1945. By that year it was hailed as an event if an anopheline larva was collected within the control perimeter about the military areas on Guadalcanal; eight years later, although a little larvical spraying was being carried out in desultory fashion at Honiara (Point Cruz)—by natives working without proper supervision and having only a hazy idea as to what constitutes an anopheline breeding place—we were able to collect blooded *An. farauti* not only in the town area in general but even in a ward of the hospital. Little or nothing is being done with regard to the control of dangerous mosquitoes on many of the more isolated islands of Polynesia, too, and the picture of filariasis transmission on such atolls as those of the Tokelau Group has not changed for the better since pioneer surveys upwards of a quarter of a century ago.

Material improvements in this situation might be forthcoming following the adoption of biological control measures based upon the findings presented herein. Thus far, the major achievements in mosquito control by means of natural enemies have involved the use of fishes such as *Gambusia* spp. and *Lebiasina reticulata* against mosquitoes breeding in surface waters. Of all the animals other than fishes which have been tried out, the only ones to show promise following their introduction to new localities are the species of *Toxorhynchites* (Culicidae) currently being employed against *Aedes pseudoscutellaris* and *A. polynesiensis* in Fiji and *A. albopictus* in Hawaii.

Although introduced mosquito fish have been established with some success in the more permanent waters of certain islands (e.g. *Lebiasina* in Aitutaki), the species concerned are not fitted for life in the transient and semipermanent waters which are a major source of both anophelines and pest culicines in the South Pacific. Local eleotrids such as the Fijian *Lairdina hopletopus*, which thrives in marshy areas and readily throws itself over moist ground to invade adjacent transient pools, might perhaps eventually prove more useful than exotic species in this region. Unfortunately, the great majority of transient pools do not lend themselves to invasion by fishes in this manner. We do not as yet know of any tropical arthropods—with the exception of mosquitoes having predaceous larvae such as species of *Culex* (*Luzia*), *Aedes* (*Mucidus*) or *Eretmapodites*—which are effective enemies of transient pool larvae. The adults of these mosquitoes bite man to a greater

or lesser extent, and they are thus unsuitable for introduction as control agents. A search for suitable predators particularly adapted to this type of habitat - with attention, perhaps, to Oriental and South American Corethrinae? - would surely be a worthwhile undertaking.

As has been indicated, the more permanent surface waters of South Pacific territories support a variety of (chiefly arthropod) predators of mosquito larvae. The most complex associations of these predators occur in Queensland and the islands of western Melanesia where, however, their value may be largely negated by the facilities for larval shelter afforded by relatively well developed aquatic floras. While it is not in any way suggested that predaceous aquatic arthropods are likely to prove useful in mosquito control if introduced into countries in which their particular ecological niches are already utilized, the general decrease in the occupancy of freshwater habitats which accompanies increasing distance eastwards from Australia provides an intriguing basis for experimental introductions of mosquito enemies. Predators of potential use in appropriate kinds of surface waters of the Solomons and New Hebrides, in view of their non-occurrence in these Groups, include such hemipterans as *Sphaeroderma* spp. (Belostomatidae) and the Indo-Malaysian *Cercometus* spp. (Nepidae), tropical Corethrinae (Gulicidae) and perhaps even so unlikely an animal as the voracious *Hydra* recorded by Hamlyn-Harris (1932) from Brisbane. The choice becomes progressively wider with increasing longitudinal distance eastwards. On such atolls as Tarawa, Funafuti and Aitutaki, besides the animals just mentioned, *Clœon* spp. (Plecoptera) and various Notonectidae (Hemiptera), Dytiscidae and Gyrinidae (Coleoptera), might be expected to prove useful. While proposing the introduction of these predators it cannot be too strongly emphasized that the success of measures of this sort would depend largely upon the maintenance of the present paucity of the aquatic phanerogam flora. None of the arthropods suggested could become medically or economically injurious. Their addition to the fauna of the region would be well worthwhile if even a slight degree of mosquito control resulted from it, and it should also be borne in mind that the establishment of such predators in the malaria-free zone would tend to decrease the chances of successful anopheline invasions.

The artificial dissemination of certain larval parasites which attack surface water mosquitoes but appear to be absent from much of the South Pacific, is also advocated. A lack of any natural immunity might render the anophelines of the Solomons and New Hebrides unusually susceptible to specific pathogens such as the microsporidian *Thelohania legei* which from time to time has caused heavy mortality amongst anopheline larvae in various localities including the U.S.A. (Kudo, 1921) and India (Sen, 1941), or suitable species of *Cordycomyces* like the one which Muspratt (1916) observed to cause the death of 95 per cent. of the *Anopheles gambiae* larvae hatching in pools which he studied in Rhodesia over a lengthy period.

So far, we have been concerned with mosquitoes which breed in surface waters. As already noted, the only arthropod predators which have yet shown any real promise as agents in control campaigns are mosquitoes of the genus *Toxorhynchites*, the larvae of which feed voraciously upon the developmental stages of their own and other species while the adults are incapable of sucking blood and thus quite harmless to man. These useful insects utilize small natural and artificial containers as larval habitats, their choice of breeding places corresponding with that of members of the *Aedes scutellaris* complex, the chief vectors of *Wuchereria bancrofti* in Polynesia. A more complete exploitation of *Toxorhynchites*, with particular attention to those species the habits of which are most closely linked with those of the *scutellaris* complex in the places in which they are endemic, might well be contemplated. Perhaps consideration might also be accorded the use of

such *Pandanus*-breeding Corethrinae—the adults of which are incapable of biting while the larvae are highly predaceous—as the species of *Corethrella* recorded from Guadalcanal (coll. no. 222); it may be that these could be employed with advantage against certain Polynesian mosquitoes, notably *Aedes fijiensis* and *A. samoanus*. Such predators could be supplemented by the introduction of suitable parasites, for example mermithid nematodes and *Coelomomyces* having the requisite host affinities.

*Coelomomyces* is particularly significant in this respect. Opinions have varied as to the potential value of fungi of this genus in mosquito control, for although individual infections are usually totally devastating to the mosquitoes concerned through destruction of the larval fat body (Keilin, 1921; Iyengar, 1935) and suppression of the imaginal buds (Iyengar, 1935), the ratio of infected to healthy larvae is often very small (Dodge, in Couch, 1945). The success of any biological control attempt utilizing *Coelomomyces* would be intimately bound up with the degree of pathogenicity, the survival period of the resting bodies of the fungus in each of the seeded larval habitats, and the percentage of lightly infected imagines surviving to spread the parasite to fresh breeding places. The question might be settled once and for all by taking advantage of the ideal conditions for the necessary field investigations afforded by isolated atolls in central Polynesia. There are no records from my own or other surveys of the presence of *Coelomomyces stegomyiae*, a species initially described from Malaya and now known from the Solomon as well, in Polynesia. *Aedes polynesiensis*, the vector of *Wuchereria* throughout the greater part of the region, is a close relative of the natural hosts of this parasite, and is the sole representative of the Culicidae on some of the remote atolls such as Nukunono, Tokelau Islands (Laird, 1955a). The possible consequences of the exposure of such isolated and non-immune populations to a lethal strain of *Coelomomyces* are something to conjure with. While it is not envisaged that anything approaching eradication would be likely to be achieved in this way, nevertheless it might prove that such biological methods can reduce isolated populations of dangerous mosquitoes below the level necessary for the continued transmission of disease-causing organisms.

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Of late years the prospect of controlling mosquitoes by biological means has been very generally neglected, largely because of the preoccupation with newly developed insecticides following the spectacular initial successes achieved with D.D.T. However, the set-backs which have now been experienced with these insecticides came in for considerable attention at the First International Symposium on the Control of Insect Vectors of Disease held at Rome in 1951 and prompted Knippling (1954) to urge upon those attending that "Further research should be conducted to develop methods of control that will supplement or replace the use of insecticides. Search for biological agents for mosquito control seems warranted. Highly virulent virus, bacterial, or protozoan organisms might be found, cultured and disseminated for controlling mosquitoes in the same way that organisms have been disseminated for controlling certain agricultural and forest pests." Surely the project utilizing *Coelomomyces* suggested herein represents as favourable an opportunity

as Rotuma and Fiji. Reference has been made to the opinion of some authorities that the presence of decapods of the family Atyidae on oceanic islands is only to be explained by postulating one-time land connections, although as has been indicated this view is open to criticism.

In between these two extremes there are many freshwater organisms which, although not confirmed wanderers, are able to take advantage of natural means of dispersal upon occasion, while others are particularly well suited to make use of human agency in extending their range. The first group includes numerous insects which, although spending most of their life in or on water, can fly quite strongly when occasion demands. Here belong many of the Hemiptera and the smaller Coleoptera. To instance only the first of these orders the families Naucoridae and Nepidae are unknown east of Queensland, the Belostomatidae drop out in New Caledonia, *Rhagovelia* does not occur south or east of the Solomons, the Hydrometridae and Corixidae reach their eastern limit in the Loyalties, the Pleidae are not known to extend east of the New Hebrides and the Mesovelidiidae are represented as far eastwards as Samoa; while of the three families ranging to the Society Islands two, the Gerridae and Notonectidae, are notable for their powers of flight, and the species of *Microvelia* (Veliidae) are minute and probably lend themselves to transportation by the agency of man. Plants referable to this group would include halophilic grasses and sedges the seeds of which might conceivably be carried across the ocean by shore birds. In the second group we must place those insects closely associated with the kinds of containers in which water is either accidentally (e.g., rubber tyres) or intentionally (e.g., casks) taken on inter-island journeys, for example the "domestic" mosquitoes and chironomid midges of the genus *Tendipes*; organisms including small oligochaetes, hecid midges such as *Forcipomyia*, and plants of the family Lemnaceae which may be carried about with aquatic phanerogams valued as food or for their ornamental appearance; and, of course, those insects which stow away as adults aboard aircraft. Representatives of both the groups of organisms considered herein have shared the colonization of the water bodies of such strictly oceanic islands as Aitutaki and the atolls with the habitually wide-ranging plants and animals, and have contributed to the augmentation of the fauna and flora of the high islands since these attained their present isolation.

Just as the successive oceanic barriers encountered moving out across the tropical South Pacific away from the centres of distribution to westward each marks a further diminution of the aquatic fauna and flora, similar consequences result from the interposition of relatively minor sea gaps between high islands and adjacent low islands (e.g., New Caledonia and Uvea) and between high islands of individual groups. Thus there is a southward decrease from 18 species of mosquitoes on Espiritu Santo to nine (at least insofar as is known) at Aneityum, the southernmost island of the New Hebrides chain, although the latter island offers the whole range of larval habitats available on the former one. Of course the non-occurrence of certain aquatic organisms in particular regions or islands is sometimes to be explained on ecological grounds rather than by reasons of isolation. Cases in point are the prevalence of halophilic algae in atoll ponds, the paucity of desnids on coral islands where the surface waters are too hard for all but a few of these acidophilic algae, and the absence of *Anopheles farauti* from Tutuba because of a lack of suitable larval habitats.

Except as otherwise noted for specific islands such as Ait with its lack of lush undergrowth and the smaller atolls with their limited range of actual and potential mosquito larval habitats, coastal ecological conditions for aquatic organisms do not vary greatly from Queensland to central and eastern Polynesia. Most of this region, and most of the territories visited during these surveys, lie between the equator and 20°S latitude, and longitudinal distance from west to east is the most important single factor limiting plant and animal distribution. The fauna

and flora of larval habitats become less and less complex as one moves eastwards, the resultant deficiencies being most strongly marked in the higher groups of the aquatic animals and plants and least evident in the Algae, Protozoa and other small organisms. Thus, as increasing isolation renders freshwater habitats less and less fully utilized by all but the lowlier aquatic organisms, we notice more and more unoccupied niches ready to cater to all the requirements of a variety of as-yet absent plants and animals. Highly significant conclusions regarding mosquito distribution and ecology depend upon this biogeographic situation.

The first of these conclusions concerns the distribution of anophelines. It is obvious that Buxton's Line, instead of denoting a boundary between two major zoogeographical regions as does Wallace's Line, merely records one particular phase in the progressive reduction of a regional flora and fauna under the influence of increasing longitudinal distance from west to east. It indicates the eastward limits so far attained by the anophelines; similar "lines" could with equal justification be ruled further and further to the east to fit the facts of distribution of other mosquitoes or for that matter of a variety of animals from mayflies to amphibians, or to mark the easternmost locality—Samoa—where mosquitoes utilizing *Pandanus* and *Colocasia* leaf axils occur. As has been shown, the larval habitats of *Anopheles farauti* fall within the range of those of *Culex annulirostris*, which, through its ability to avail itself of human transportation, is now established throughout Polynesia. However, the latter species exhibits rather more catholic habits, its larvae tolerating somewhat higher water temperatures than do those of *An. farauti*, being found more frequently in large simple containers and being unaffected by the presence of oxygenated fests of blue-green algae which appear inhibitory to this anopheline. Accepting these observations, it is contended that the presence of *C. annulirostris* in the anopheline-free islands of the region is generally indicative of the presence of larval habitats that would suit *An. farauti*. Plausible ecological arguments may be invoked to explain the continued absence of this mosquito from islands within or near the malaria perimeter such as Tutuba, Ait and Uvea, and a simple lack of potential larval habitats protects Bellona and many of the small atolls. Climatic considerations together with other ecological factors weigh against the further southward dispersal of *An. farauti* in Queensland, and it is possible that New Caledonia lies a little too far to the south to favour the general establishment of the species; although this mosquito might be able to establish itself in certain areas, particularly in the wet bush on the eastern coast of the island. New Zealand is almost certainly too far south to be in any danger, although it is not unlikely that less dangerous anophelines which thrive under temperate conditions—the Australian *An. annulipes*, for example—could become established in the warmer parts of the country. The important consideration for the area covered by the present investigations is that it cannot be claimed that any general factor other than isolation is operating to prevent the extension of the range of *An. farauti* to those tropical islands east of Buxton's Line where the requisite ecological conditions present themselves. This line should not be regarded as indicative of a barrier beyond which anophelines are destined never to advance, but rather as an ever-present reminder of the proximity of a dangerous species of *Anopheles* to a zone in which it would flourish; for following its introduction into such groups as Fiji, Samoa and the Cook Islands *An. farauti* would not be subject to the attacks of any parasites to which it is not already exposed in its present area of distribution and would furthermore be favoured by a generally lower degree of competition and a higher degree of freedom from predators consequent upon the decreasing utilization of larval habitats by aquatic animals.

Once so formidable a vector of *Plasmodium* became established in the existing malaria-free zone of the South Pacific, opportunities for becoming infected from gametocyte carriers, such as Fijian troops who have contracted malaria on service in Malaya, would sooner or later arise. Primary epidemics might then be initiated, with devastating consequences. It is therefore considered that in the face of the

continuing development of the economic life of Fiji and of the major island groups of tropical Polynesia, and the inevitable growth of speedier and more frequent transportation links with the outside world, an unceasing vigilance to guard against accidental introductions of anophelines through human agency is the price that must be paid if these territories are to remain free from the threat of malaria.

The second conclusion to be drawn from the data submitted herein is that—at least until mosquito control is enforced far more satisfactorily in the region than at present—nothing should be done that will serve to increase the numbers of larval habitats or else render ones already existing more suited to mosquito breeding than they are to-day. Such mosquito predators and competitors as now occur in the central and easterly islands of the South Pacific succeed in keeping a partial check on mosquito breeding both by virtue of their abundance in individuals and the lack of sheltering vegetation. It cannot be too strongly emphasized that future introductions of aquatic plants into these islands should not be contemplated without the most mature examination of the possible consequences—rises in mosquito populations through the multiplication of places affording larvae shelter from biological control agents already present, the enhancement of the chances of successful establishments of introduced anophelines, and the partial if not complete negation of any future plans for biological control using exotic predators. It is urged that the South Pacific Commission authorities, in their laudable desire to supplement human vegetable food and pig fodder in the region by introducing the aquatic Sweet Potato *Ipomoea aquatica* Forsk from South East Asia (Barraud, 1955), are unwittingly laying the foundations for greatly increased mosquito hazards in the islands they are endeavouring to assist. A further S.P.C. project, the encouragement of the pond culture of the food fish *Tilapia mossambica* Peters in their area of operation (van Pel, 1955, 1955a), is also fraught with risk. Anyone who has had personal experience of the anopheline and culicine control problems posed by the domestic fish ponds and hyacinth ponds of South East Asia must view these developments with grave concern. While it is true that if fish ponds are maintained in a vegetation-free state, any predators present, including the fish themselves, will keep mosquito breeding down to a minimum, in actual practice various aquatic plants including *Ipomoea* and Water Hyacinth are frequently cultivated for use as fodder or else are allowed to grow unchecked. It has already been suggested that *Tilapia* and *Ipomoea* should be cultivated in the same South Pacific ponds in order to increase the ultimate yield of these (Barraud, 1955). If this should be allowed to happen the resultant high intersection values (see pp. 57–58) will favour mosquito breeding, and the wholesale creation of large numbers of additional permanent ponds in the settled areas of New Caledonia, Fiji and the Cook Islands, the islands initially concerned (van Pel, 1955), will both increase local mosquito populations and render the larval environment still more suitable for anophelines. Van Pel (1955) emphasized that *Tilapia mossambica* flourishes in brackish ponds as well as freshwater ones. Brackish fish ponds and prawn ponds in Malaysia often become choked with algae of the genus *Enteromorpha*, and *Anopheles sundaeicus* (Rodenwaldt), perhaps the most dangerous malaria vector of South East Asia, then breeds unchecked. A warning has already been given that the salt marshes of New Caledonia might prove open to invasion by *An. sundaeicus* brought in from the north by aircraft (Laird, 1951a), and it is surely most undesirable that anything should be done to create still better breeding conditions for this mosquito.

Finally, the matter of the control of dangerous mosquitoes already present in various parts of the South Pacific must be considered. Experience during World War II proved that even so ubiquitous a species as *An. farauti* can be brought under control by employing modern insecticidal techniques on the grand scale. Full control, with the complete cessation of malaria transmission, was achieved in certain localities, notably those parts of Guadalcanal and Espiritu Santo where large numbers of troops were stationed. The necessary measures are, however, highly

expensive; and they must be kept in force continuously. Thus only two months after the withdrawal of troops from Nissan Island, Territory of New Guinea, and the cessation of D.D.T. larvicide which had been enforced for some 18 months during 1944-45, Laird (1952) found extremely heavy concentrations of *An. farauti* larvae in all kinds of surface waters throughout the former control areas. Very few predators were in evidence even in the more permanent ponds. They as well as the mosquitoes had been affected by larvicide. They were taking materially longer to re-invade the area from foci outside the old control perimeter, and in the meantime the mosquitoes, with their much briefer life history, were developing unchecked. More recently a much more serious consequence of the continued use of chemical control agents, the development of resistance to residual insecticides, has become apparent in many parts of the world. Fears are already being expressed in some quarters that acquired resistance to the newer insecticides on the part of mosquitoes may very adversely affect current and contemplated regional control programmes.

Adequate mosquito control campaigns based on the use of larvicides and residual chemical sprays are, in any case, extremely expensive and beyond the purse of the less developed Pacific territories. It is true that filariasis control through anti-mosquito measures has made real headway in some areas, notably in the more developed islands of Viti Levu, Rarotonga and Tahiti (Beye, 1953), and that efforts are being made to apply residual spraying techniques to anopheline control in New Guinea (Black, 1955). On the other hand, anopheline control in the areas of European settlement in the Solomons and New Hebrides has slipped back badly since 1945. By that year it was hailed as an event if an anopheline larva was collected within the control perimeter about the military areas on Guadalcanal; eight years later, although a little larvical spraying was being carried out in desultory fashion at Honiara (Point Cruz)—by natives working without proper supervision and having only a hazy idea as to what constitutes an anopheline breeding place—we were able to collect blooded *An. farauti* not only in the town area in general but even in a ward of the hospital. Little or nothing is being done with regard to the control of dangerous mosquitoes on many of the more isolated islands of Polynesia, too, and the picture of filariasis transmission on such atolls as those of the Tokelau Group has not changed for the better since pioneer surveys upwards of a quarter of a century ago.

Material improvements in this situation might be forthcoming following the adoption of biological control measures based upon the findings presented herein. Thus far, the major achievements in mosquito control by means of natural enemies have involved the use of fishes such as *Gambusia* spp. and *Lebiasina reticulatus* against mosquitoes breeding in surface waters. Of all the animals other than fishes which have been tried out, the only ones to show promise following their introduction to new localities are the species of *Toxorhynchites* (Culicidae) currently being employed against *Aedes pseudoscutellaris* and *A. polynesiensis* in Fiji and *A. albopictus* in Hawaii.

Although introduced mosquito fish have been established with some success in the more permanent waters of certain islands (e.g. *Lebiasina* in Aitutaki), the species concerned are not fitted for life in the transient and semipermanent waters which are a major source of both anophelines and pest culicines in the South Pacific. Local eleotrids such as the Fijian *Lairdina hopletopus*, which thrives in marshy areas and readily throws itself over moist ground to invade adjacent transient pools, might perhaps eventually prove more useful than exotic species in this region. Unfortunately, the great majority of transient pools do not lend themselves to invasion by fishes in this manner. We do not as yet know of any tropical arthropods—with the exception of mosquitoes having predaceous larvae such as species of *Culex* (*Lutzia*), *Aedes* (*Mucidus*) or *Eretmapodite*—which are effective enemies of transient pool larvae. The adults of these mosquitoes bite man to a greater

or lesser extent, and they are thus unsuitable for introduction as control agents. A search for suitable predators particularly adapted to this type of habitat - with attention, perhaps, to Oriental and South American Corethrinae? - would surely be a worthwhile undertaking.

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as could be envisaged for attempting the control of a medically important mosquito by means of parasites. Should the undertaking end in failure little would be lost as the outlay would be a comparatively light one; but if it should have a successful conclusion the way would lie open for allied studies elsewhere. It would of course be first necessary to make detailed surveys of the occurrence and pathogenicity of appropriate parasites, and of the effectiveness of all kinds of mosquito predators, in all parts of the world. In the process our knowledge of mosquito ecology would be immeasurably increased, and applications of this new knowledge might well prove of far-reaching significance in regard to control, particularly in territories lacking the economic structure necessary for the underwriting of the costly anti-mosquito measures now in vogue.

#### LITERATURE CITED

- ADAMSON, A. M., 1935. Non-marine Invertebrate Fauna of the Marquesas (Exclusive of Insects). *B. P. Bishop Museum, Honolulu, Occ. Pprs.*, 11, (10), 1-39.  
 ADIE, , 1904. Ref. in *Ind. Med. Gaz.*, Vol. 39, not seen, but quoted in detail by Theobald, F. V., 1907.
- AMOS, D. W., 1947. *Mosquito Control Training Manual*. Suva: Govt. Press, 1-44.
- ANON., 1936. Report of Cook Islands Administration, 1935-36. N.Z. *Parl. Com. Pprs.*, no. 1-A.3, 1-31.
- , 1937. Report of Cook Islands Administration, 1936-37. *Ibid.*, no. 1-A.3, 1-23.
- , 1947. *Malaria Control on Impounded Waters*. U.S. Federal Security Agency: U.S. Pub. Hlth. Ser. and T.V.A., xiii, 1-422.
- BAILEY, S. F. and BOHART, R. M., 1952. A Mosquito Survey and Control Programme in Guam. *J. econ. Ent.* 45, (6), 917-932.
- BAKER, J. R., 1929. *Man and Animals in the New Hebrides*. London: Routledge, xiv + 1-200.
- BALFOUR-BROWNE, J. 1945. Aquatic Coleoptera of Oceania (Dytiscidae, Gyrinidae, and Palpidae). *B. P. Bishop Museum, Honolulu, Occ. Pprs.*, 18, (7), 103-132.
- BARNOUR, T., 1923. The Frogs of the Fiji Islands. *Proc. Acad. nat. Sci. Philad.*, 75, 111-115.
- BARRAUD, J. 1955. Easily-grown Semi-aquatic Vegetable is Highly Edible. *Quart. Bull., South Pacific Commission*, 5, (3), 19-20; 29.
- BARY, B. M., 1950. Studies on the Freshwater Ciliates of New Zealand. Part II. An Annotated List of Species from the Neighbourhood of Wellington. *Trans. Roy. Soc. N.Z.*, 78, (2-3), 311-323.
- BATES, M., 1949. *The Natural History of Mosquitoes*. New York: Macmillan, xv + 1-379.
- BATSCHEKINSKY, P. E., 1927. Zur Biologie der Larven von Anopheles und Culex im Zusammenhang mit der Methode der biologischen Analyse von Kokwitz-Marsson und Infektionsversuchen der Larven mit Schimmelzitosporen. (Abstract in *Rev. Appl. Ent.*, 15, 153.)
- BAYLIS, H. A., 1936. *Nematoda. Vol. I. Ascaroidea and Strongyoidea. Fauna of British India*. London: Taylor and Francis, xxxvi + 1-408.
- BRATTIE, M. V. F. and HOWLAND, L. J., 1929. The Bionomics of some Tree-hole Mosquitoes. *Bull. ent. Res.*, 20, 45-58.
- BELKIN, J. N., 1945. A Revised List of the Common Mosquitoes of Guadalcanal with Notes on Bionomics. Cyclostyled Report, U.S. 420th Medical Composite Unit, 1-9.
- , 1950. Mosquitoes of the Genus *Tripteroides* in the Solomon Islands. *Proc. U.S. Nat. Mus.*, 100, 201-271.
- , 1953. Mosquitoes of the Genus *Uranotaenia* in the Solomon Islands (Diptera: Culicidae). *Pacific Science*, Honolulu, 7, 312-391.
- , 1955. The *Tripteroides coaledonius* Complex of Mosquitoes in Melanesia (Diptera: Culicidae). *Ibid.*, 9, (2), 221-246.
- , KNIGHT, K. L. and ROZEBROOK, L. E., 1945. Anopheline Mosquitoes of the Solomon Islands and New Hebrides. *J. Parasit.*, 31, (4), 241-265.
- BENTLEY, C. A., 1910. The Natural History of Bombay Malaria. *J. Bombay Nat. Hist. Soc.* 20, 392-422.
- BERGEY, D. H., 1934. *Bergey's Manual of Determinative Bacteriology*. Fourth Ed. Baltimore: Williams and Wilkins, xvi + 1-664.
- BERLAND, L., 1934. Les araignées du Pacifique. pp. 155-180 in Contribution à l'étude du peuplement zoologique et botanique des îles du Pacifique. *Soc. biogéogr.*, IV. Paris: Lechevalier.
- BEYER, H. K., 1953. Control of Bancroftian Filariasis in the South Pacific. Part VI (73-88) of *Filariasis in the South Pacific*. Noumea: South Pacific Commission, vii + 1-108.

- BHATIA, B. L., 1936. *Protozoa: Ciliophora. Fauna of British India*. London: Taylor and Francis, xxii + 1-193.
- BICK, G. H., 1951. The Ecology of the Mosquito Larvae of New Guinea. *Pacific Science*, 5, (1), 392-431.
- BIRGE, E. A., 1943. The Water Fleas (Cladocera). Chapter XXII (676-740) of *Fresh-water Biology*, Ward, H. B., and Whipple, G. C. New York: John Wiley. ix + 1-1111.
- BISHOP, S. C., and HART, R. C., 1931. Notes on some Natural Enemies of the Mosquito in Colorado. *J. N. Y. ent. Soc.*, 39, 151-157.
- BLACK, R. H., 1950. Anophelism without Malaria in Northern Australia: A Malaria Survey of Part of the Northern Territory and the East Kimberleys District. *Ann. trop. Med. Parasit.*, 44, (3), 207-211.
- — — 1952. *A Survey of Malaria in the British Solomon Islands Protectorate*. Noumea: South Pacific Commission, Technical Paper No. 33, I-27.
- — — 1955. Rural Malaria Control in the S.W. Pacific. *Quart. Bull., South Pacific Commission*, 5, (2), 7 and 16.
- BODMAN, M. T., and GUNNISON, N., 1930. Some Habitats of Eggs of *Aedes vexans*. *J. econ. Ent.*, 13, (4), 517-518.
- BOHARÉ, R. M., 1946. New Species of Mosquitoes from the Marianas and Okinawa. *Proc. biol. Soc. Wash.*, 59, 39-46.
- — — INGRAM, R. L., 1946. *Mosquitoes of Okinawa and Islands in the Central Pacific*. Washington: Navmed. 1055. Bu. Med. and Surgery, Navy Dept. ii + 1-110.
- BONNE-WESTLER, J., and SWILLENGREBEL, N. H., 1953. *The Anopheline Mosquitoes of the Indo-Australian Region*. Amsterdam: de Bussy, I-504.
- BONNET, D. D., and HUTCHINS, S. M. K., 1951. The Introduction of *Toxorhynchites brevipalpis* Theobald into the Territory of Hawaii. *Proc. Hawaii. ent. Soc.*, 14, (2), 237-242.
- BOYD, M. F., 1930. *An Introduction to Malariaiology*. Cambridge, U.S.A.: Harvard Univ. Press. xiv + 1-437.
- BRYAN, E. H., 1934. A Review of the Hawaiian Diptera, with Descriptions of New Species. *Proc. Hawaii. ent. Soc.*, 8, (3), 399-468.
- BUDDINGTON, A. R., 1941. The Nutrition of Mosquito Larvae. *J. econ. Ent.*, 34, (2), 275-281.
- BUNTON, J. A., and BACLAND, O. P., 1952. Some Species of Mosquitoes Reared from Dry Materials. *Mosquito News*, 12, (3), 209-214.
- BUXTON, P. A., 1926. The Depopulation of the New Hebrides and other Parts of Melanesia. *Trans. Roy. Soc. trop. Med. Hyg.*, 19, 420-454.
- — — 1930. Description of the Environment. *Insects of Samoa*, IX, Fasc. 1, 1-32. (Brit. Mus. (Nat. Hist.). 1927-35).
- — — 1935. Summary. *Insects of Samoa*, IX, Fasc. 2, 33-104.
- — — and HOPKINS, G. H. E., 1927. *Researches in Polynesia and Melanesia*. Parts I-IV. London: No. 1 Mem. Ser. Lond. Sch. Hyg. Trop. Med., xi + 1-260.
- CARL, G. C., 1937. Flora and Fauna of Brackish Water. *Ecology*, 18, (3), 446-453.
- CARPENTER, K. E., 1928. *Life in Inland Waters with Special Reference to Animals*. New York: Macmillan. xiii + 1-267.
- CAWSTON, F. G., 1929. The Resistance of Limnaeidae to Desiccation. *Trans. Roy. Soc. trop. Med. Hyg.*, 22, (1), 335-338.
- CHAPMAN, V. J., 1941. *An Introduction to the Study of Algae*. Cambridge: University Press, x + 1-387.
- CHLESMAN, E., 1927. *Islands Near the Sun*. London: Witherby, 1-236.
- CHRISTOPHERSEN, E., 1935. Flowering Plants of Samoa. *B. P. Bishop Museum, Honolulu*, Bull. 128, 1-221.
- — — 1938. Flowering Plants of Samoa. *Ibid.*, Bull. 154, 1-77.
- CLEGG, J., 1952. *The Freshwater Life of the British Isles*. London: Warne, 1-351.
- COOGLISHAW, L. T., 1926. Relationship of Plankton to Anopheline Larvae. *Amer. J. Hyg.*, 6, 556-569.
- COOKE, A. H. (1895), 1913. Molluscs. pp. 1-459 in Vol. III, *The Cambridge Natural History*. London: Macmillan.
- COOLING, L. E., 1923. Mosquito-larvivorous Fishes in Relation to Mosquito Reduction Work in Australia. *Health*, 1, (4), 94-98.
- — — 1927. Australian Fish as Mosquito Larvae Destroyers. *Ibid.*, 6, (1), 11-12.
- COUCH, J. N., 1915. Revision of the Genus *Coelomomyces*, Parasitic in Insect Larvae. *J. Eliza Mitchell Sci. Soc.*, 61, 124-136.
- — — and DOORST, H. R., 1917. Further Observations on *Coelomomyces*, Parasitic on Mosquito Larvae. *Ibid.*, 63, 69-79.
- DAGGY, R. H., 1915. The Biology and Seasonal Cycle of *Anopheles farauti* on Espiritu Santo, New Hebrides. *Ann. ent. Soc. Amer.*, 38, (1), 1-13.
- DARWIN, C., (1859), 1888. *On the Origin of Species by Means of Natural Selection*. 6th Ed. London: Murray, xxi + 1-450.

- DAVIS, T. R. A., 1949. Malaria Control in the Cook Islands. *N.Z. med. J.*, 48, 362-370.
- DEMPWOLFF, 1904. Bericht über eine Malaria-Expedition nach Deutsch-Neu-Guinea. *Zeitschr. f. Hyg. u. Infektionskrankh.*, 47, 81-132.
- DUNCAN, J. T., 1926. On a Bacterial Principle Present in the Alimentary Canal of Insects and Arachnids. *Parasitol.*, 18, 238-252.
- DYE, L., 1905. Les parasites des Culicidae. *Arch. parasit.*, 9, 5-77.
- EDMONDSON, C. H., 1910. A Report on the Fresh-water Protozoa of Tahiti. *Science*, n.s., 32, 349-351.
- 1929. Hawaiian Atyidae. *B. P. Bishop Museum, Honolulu, Bull.*, 66, 1-36.
- EDWARDS, F. W., 1922. Mosquito Notes.—III. *Bull. ent. Res.*, 13, 75-102.
- 1924. Synopsis of the Adult Mosquitoes of the Australasian Region. *Ibid.*, 14, 351-401.
- 1929. Mosquito Notes.—VIII. *Ibid.*, 20, (3), 321-313.
- 1932. Diptera, fam. Culicidae. *Genera Insectorum*, fasc. 191, 1-258. Brussels: Louis Desmet-Verteneuil.
- 1935. Mosquito Notes. XII. *Bull. ent. Res.*, 26, 127-136.
- ERIKSENBERG, G. C., 1832. Beiträge zur Kenntnis der Organisation der Infusorien und ihrer geograph. Verbreitung besonders in Sibirien. *Abhandl. d. Königl. Akad. d. Wissenschaften zu Berlin*, a. d. J. 1830 (1832), 1-88.
- ENGELMANN, T. W., 1895. Ref. in *Arch. néerl. Sci.*, Vol. 28, not seen, but quoted by Wiggleworth, V. B., 1939. *The Principles of Insect Physiology*, p. 197.
- ESAKI, T., 1928. Hemiptera. *Insects of Samoa*, II. *Fasc.* 2, 67-80.
- FARNER, D. S., and BOHART, R. M., 1941. Three New Species of Australasian Aedes (Diptera, Culicidae). *Proc. biol. Soc. Wash.*, 57, 117-122.
- FORD, E., 1950. The Malaria Problem in Australia and the Australian Pacific Territories. *Med. J. Aust.*, 1, (23), 749-760.
- FOWLER, H. W., 1932. Fresh-water Fishes from the Marquesas and Society Islands. *B. P. Bishop Museum, Honolulu, Oce. Pap.*, 9, (25), 1-11.
- FRASER, F. G., 1927. Odonata. *Insects of Samoa*, VII. *Fasc.* 1, 19-43.
- FRICK, K. E., 1949. The Biology of *Micromyia capitata*, Guérin, 1857, in the Panama Canal Zone and its rôle as a Predator on Anopheline Larvae (Diptera: Culicidae). *Ann. ent. Soc. Amer.*, 42, 77.
- FROMISHER, M., 1949. *Fundamentals of Bacteriology*. Philadelphia: Saunders. xxii + 1-936.
- FROUIN, W. G., 1933. Natural History of *Culex innotatus* (Wlk.). (Diptera, Culicidae), in Alaska. *Trans. Amer. micr. Soc.*, 72, (2), 105-118.
- GALLIARD, H., MILLER, R., and ROBINSON, W. A., 1949. Recherches sur la filariose à Tahiti (Note préliminaire). *Bull. Soc. Path. exot.*, 42, (5), 174-178.
- GARNHAM, P. C. C., HARPLER, J. O., and HIGHTON, R. B., 1916. The Mosquitoes of the Kaimosi Forest, Kenya Colony, with Special Reference to Yellow Fever. *Bull. ent. Res.*, 36, 473-496.
- GENDRE, E., 1909. Sur des larves de *Mermis* parasites des larves du *Stegomyia fasciata*. *Bull. Soc. Path. exot.*, 2, 106-108.
- GERMAIN, L., 1931. Études sur les faunes malacologiques insulaires de l'Océan Pacifique. In Contribution à l'étude du peuplement zoologique et botanique des îles du Pacifique. *Soc. biogéogr.*, IV. Paris: Lechevalier. (89 153).
- GIBBINS, E. G., 1932. Natural Malaria Infection of House-frequenting *Anopheles* Mosquitoes in Uganda. *Ann. trop. Med. Parasit.*, 26, (3), 239-265.
- 1942. On the Habits and Breeding-places of *Aedes (Stegomyia) simpsoni* Theobald in Uganda. *Ibid.*, 36, (1), 151-160.
- GILES, G. M., 1902. *A Handbook of the Gnats or Mosquitoes giving the Anatomy and Life History of the Culicidae*. London: John Bale, Sons and Danielsson, xii + 1-530.
- GILL, W. W., 1885. *Jottings from the Pacific*. London: Religious Tract Society, 1-248.
- GUILLIN, C. M., HILARY, G. P., and BOLLIN, W. B., 1941. The Necessity of a Low Oxygen Concentration for the Hatching of Aedes Mosquito Eggs. *J. Cell. Comp. Physiol.*, 17, 193-202.
- GLEN LISTON, W., 1901. A Year's Experience of the Habits of Anopheles in Ellinchpur. *Ind. Med. Gaz.*, 36, 361-366.
- GOLDACRE, R. J., 1949. Surface Films on Natural Bodies of Water. *J. Anim. Ecol.*, 18, (1), 36-39.
- GOOD, R., 1953. *The Geography of the Flowering Plants*. 2nd. Ed. London: Longmans, Green and Co., xiv + 1-152.
- GRAHAM, D. H., 1939. Mosquito Life in the Auckland District. *Trans. roy. Soc. N.Z.*, 69, (2), 210-221.
- GRANT, A. M. B., 1933. A Medical Survey of the Island of Nauru. *Med. J. Aust.*, 1, 113-118.
- GUILLUMET, A., 1948. *Flora analytique et synoptique de la Nouvelle-Calédonie. Phanérogames*. Paris: Office de la recherche scientifique coloniale. I 369

- HADDOW, A. J., 1942. The Mosquito Fauna and Climate of Native Huts at Kisumu, Kenya. *Bull. ent. Res.*, 33, 91-142.
- — — 1946. The Mosquitoes of Bwamba County, Uganda. IV.—Studies on the Genus *Eretmapodites*, Theobald. *Ibid.*, 37, (1), 57-62.
- — — 1948. The Mosquitoes of Bwamba County, Uganda. VI.—Mosquitoes Breeding in Plant Axils. *Ibid.*, 39, (2), 185-212.
- — — VAN SOMEREN, E. C. C., LUNSDALE, W. H. R., HARPER, J. O., and GILLETT, J. D., 1951. The Mosquitoes of Bwamba County, Uganda. VIII.—Records of Occurrence, Behaviour and Habitat. *Ibid.*, 42, (2), 207-238.
- NAWA, Y., 1940. Small-animal fauna in the Colocasia-field of Yap Island. *Kagaku Nanya*, 2, (3), 12-16.
- HAMLYN-HARRIS, R., 1928. The Relation of certain Algae to Breeding Places of Mosquitoes in Queensland. *Bull. ent. Res.*, 18, (4), 377-389.
- — — 1929. The Relative Value of Larval Detractors and the Part They Play in Mosquito Control in Queensland. *Proc. roy. Soc. Qd.*, 41, (3), 23-38.
- — — 1930. The Consideration of certain Factors as Potentiliaries in Mosquito Control in Australia. *Ibid.*, 42, (10), 86-105.
- — — 1932. Some further Observations on *Chara fragilis* in Relation to Mosquito Breeding in Queensland. *Ann. trop. Med. Parasit.*, 26, (1), 519-524.
- HARMS, S. F., 1901. Polyzoa. pp. 463-533 in Vol. II, *The Cambridge Natural History*. London: Macmillan.
- HARTOG, M., 1901. Rotifers. pp. 197-238 in Vol. II, *The Cambridge Natural History*. London: Macmillan.
- HASTINGS, A. B., 1929. Notes on some Little-known Phytactolacmainous Polyzoa and Description of a New Species from Tahiti. *Ann. Mag. nat. Hist.*, 10th Ser., 3, 300-310.
- HEARLE, E., 1926. The Mosquitoes of the Lower Fraser Valley, British Columbia, and their Control. *Canad. Nat. Rev. Council Rept.*, 17, 1-91.
- HELU, K., and ILUNGA, S., 1952. Mosquito Survey at Foa Island of Ha'apai Group. *Tongan Medical Journal* (cyclostyled, pages un-numbered).
- HEMSLEY, W. B., 1891. The Flora of the Tonga or Friendly Islands. *J. Linn. Soc. (Bot.)*, 30, 158-217.
- HERMANT, P., and CLEMENT, R. W., 1929. Report of a Mission entrusted with a Survey of Health Conditions in the Pacific Islands. *Healh. Org. League of Nations*, C.II. 829, 1-116.
- HESS, A. D., and HALL, T. F., 1945. The Relation of Plants to Malaria Control on Impounded Waters with a Suggested Classification. *J. nat. Malar. Soc.*, 4, (1), 20-16.
- HESSE, R., ALLEE, W. C., and SCHMIDT, K. P., 1951. Ecological Animal Geography. 2nd Ed. New York: John Wiley. xiii + 1 715.
- HINMAN, E. H., 1930. A Study of the Food of Mosquito Larvae (Culicidae). *Amer. J. Hyg.*, 12, (1), 238-270.
- — — 1934. Predators of the Culicidae. I. The Predators of Larvae and Pupae Exclusive of Fish. *J. Trop. Med. Hyg.*, 37, 129-134.
- — — 1934a. Predators of the Culicidae. II. Predators of Adult Mosquitoes. *Ibid.*, 37, 145-150.
- HINTZ, H. W., 1951. The Role of certain Arthropods in Reducing Mosquito Populations of Permanent Ponds in Ohio. *Ohio J. Sc.*, 51, (5), 277-279.
- HOBBIN, H. I., 1930. Spirits and the Healing of the Sick in Ontong Java. *Oceania*, 2, 1-23.
- HOPKINS, G. H. E., 1952. *Mosquitoes of the Ethiopian Region. I. Larval Bionomics of Mosquitoes and the Taxonomy of Culicinae Larvae*. 2nd Ed. London: Brit. Mus. (Nat. Hist.), viii + 1-355.
- HORSTAL, W. R., 1954. A Migration of *Aedes vexans* Meigen. *J. econ. Ent.*, 47, (3), 544.
- — — and PORTER, D. A., 1946. Biologies of Two Malaria Mosquitoes in New Guinea. *Ann. ent. Soc. Amer.*, 39, (4), 519-560.
- HOWARD, L. O., DYAR, H. G., and KNAB, F., 1912. *The Mosquitoes of North and Central America and the West Indies*. Washington: Carnegie Inst. Publ. No. 159. Vol. I, vii + 1-520.
- HOWLAND, J. J., 1930. Biometrical Investigation of English Mosquito Larvae with Special Reference to their Algal Food. *J. ecol.*, 18, (1), 81-125.
- HULL, W. B., 1952. Mosquito Survey of Guam. *U.S. Armed Forces Med. J.*, 3, (9), 1287-1295.
- INGLIS, J., 1887. *In the New Hebrides . . . 1850-77*. London: Nelson. xvi + 1-352.
- — — 1890. *Bible Illustrations from the New Hebrides*. London: Nelson. xi + 1-356.
- IVYNGAR, M. O. P., and IVYNGAR, M. O. T., 1932. On a Characeum growing on *Anopheles* Larvae. *The New Phytologist*, 31, 66-69.

- IVENGAR, M. O. T., 1929. Parasitic Nematodes of *Anopheles* in Bengal. p. 128 in Vol. III, *Trans. F.E.A.T.M.*, 7th. Congr. India, 1927.
- — — 1935. Two New Fungi of the Genus *Coelomomyces* Parasitic in Larvae of *Anopheles*. *Parasitol.*, 27, 440-449.
- — — 1954. Distribution of *Filaria* in the South Pacific Region. Noumea: South Pacific Commission, Technical Paper No. 66, vi + 1-52.
- JENKINS, D. W., and KNIGHT, K. L., 1950. Ecological Survey of the Mosquitoes of Great Whale River, Quebec. *Proc. ent. Soc. Wash.*, 52, (5), 209-223.
- — — 1952. Ecological Survey of the Mosquitoes of Southern James Bay. *Amer. Midl. Nat.*, 47, (2), 456-468.
- JETTMAR, H. M., von, 1917. Mikroben als Feinde von Stechmückenlarven. *Acta Tropica*, 4, 193-208.
- JOHNSON, H. P., 1903. In Appendix to: Snith, J. E., 1903. Report on the Mosquito Investigations. *Rep. Ext. Dept. N.J. Agric. Coll. Expt. Sta. for 1902*, 509-593.
- KAHN, A., 1930-35. Uriere oder Protozoa. I Wimpertiere oder Ciliata (Infusoria). Teil 18, i-180, 1930; Teil 21, 181-398, 1931; Teil 25, 399-650, 1932; Teil 30, 651-886, 1935. *Die Tierwelt Deutschlands*, ed. F. Dahl. Jena: Fischer.
- KERLIN, D., 1921. On a New Type of Fungus: *Coelomomyces stegomyiae* n.g., n.sp., Parasitic in the Body Cavity of the Larva of *Stegomyia (Stegomyia) cutellari*, Walker (Diptera, Neurotoda, Culicidae). *Parasitol.*, 15, 226-234.
- — — 1927. On *Coelomomyces stegomyiae* and *Zografa notonectae*, Fungi Parasitic in Insects. *Parasitol.*, 19, (4), 365-367.
- KLEISTER, A., 1921. Die sessilen peritrichen Infusorien und Suctorian von Basel und Umgebung. *Rer. Suise Zool.*, 28, 221-341.
- KING, W. V., 1949. Anophelines of the Australasian Region. Chapter 21, pp. 506-525 in *Malariaiology*, ed. M. F. Boyd. Vol. I. Philadelphia: Saunders.
- KNIGHT, K. L., and HILL, W. B., 1953. The *Aedes* Mosquitoes of the Philippine Islands. III. Subgenera *Aedimorphus*, *Baikinella*, *Aedes* and *Cancratoides* (Diptera, Culicidae). *Pacific Science*, 7, (1), 453-481.
- KNIPPLING, E. F., 1954. Outlook for Future Developments in Insect Control Practices and Methods. *Int. Internat. Symposium on the Control of Insect Vectors of Disease*. Rome, 318-330.
- KUDO, R. R., 1921. Studies on Microsporidia with Special Reference to Those Parasitic in Mosquitoes. *J. Morph.*, 33, 153-193.
- — — 1922. Studies on Microsporidia Parasitic in Mosquitoes. II. On the Effect of the Parasites upon the Host Body. *J. Parasit.*, 8, 70-77.
- — — 1921. Studies on Microsporidia Parasitic in Mosquitoes. VI. On the Development of *Thelobania opacita*, a Culicinae Parasite. *Ibid.*, 11, 81-89.
- — — 1924a. Studies on Microsporidia Parasitic in Mosquitoes. III. On *Thelobania legeri* Hesse (= *Th. illinoiensis* Kudo). *Arch. Protistenk.*, 49, 147-162.
- — — 1946. *Protozoology*. 3rd. Ed. Illinois: Charles C. Thomas, xiii + 1-778.
- LAIRD, M., 1946. A Report on Material Obtained during a Mosquito Survey at Palnahnal, New Britain. *Trans. Roy. Soc. N.Z.*, 75, (4), 465-478.
- — — 1946a. Observations on *Anopheles punctulatus* Dönitz, 1901, and *Anopheles farauti* Laveran, 1902, at Palnahnal and Manginuma, New Britain, during July and August, 1945. *Ibid.*, 76, (2), 148-157.
- — — 1947. Some Natural Enemies of Mosquitoes in the Vicinity of Palnahnal, New Britain. *Ibid.*, 76, (3), 453-476.
- — — 1951. Insects Collected from Aircraft Arriving in New Zealand from Abroad. *Zool. Pubs. Vict. Univ. Coll.*, No. 11, 1-30.
- — — 1951a. The Accidental Carriage of Insects on board Aircraft. *J. Roy. Ae. Soc.*, London, 735-743.
- — — 1952. Notes on the Mosquitoes of Nissan Island, Territory of New Guinea. *Pacific Science*, 6, (2), 151-156.
- — — 1952a. Insects Collected from Aircraft Arriving in New Zealand during 1951. *J. Aviation Med.*, U.S.A., 23, 280-285.
- — — 1951. *Anopheles* and Malaria at Aneityum, New Hebrides. *Bull. ent. Res.*, 45, (2), 279-283.
- — — 1954a. A Mosquito Survey in New Caledonia and the Belep Islands, with New Locality Records for Two Species of *Gulex*. *Ibid.*, 45, (2), 285-293.
- — — 1954b. The Mosquitoes of Atutuki, Southern Cook Islands. *Ibid.*, 45, (3), 423-427.
- — — 1955. Mosquitoes and Malaria in the Hill Country of the New Hebrides and Solomon Islands. *Ibid.*, 46, (2), 273-289.
- — — 1955a. Notes on the Mosquitoes of the Gilbert, Ellice and Tokelau Islands, and on Filariasis in the latter Group. *Ibid.*, 46, (2), 291-300.
- LAMBLRT, F. J., 1930. Animal Life in the Marsh Ditches of the Thames Estuary. *P.Z.S.*, 1930, 801-808.

- LAMBERT, S. M., 1928. Medical Conditions in the South Pacific. *Med. J. Aust.*, 2, 362.  
 —— 1931. Health Survey of Russell and Bellona Islands. *Oceania*, 2, 136-173.  
 —— 1949. Malaria Incidence in Australia and the South Pacific. Chapter 35, pp. 820-830  
 in *Malariaiology*, ed. M. F. Boyd. Vol. II. Philadelphia: Saunders.
- LAMBORN, W. A., 1923. The Bionomics of some Malayan Anophelines. *Bull. ent. Res.*, 13, (2), 129-119.
- LAN-CHOU, FENG, 1933. Some Parasites of Mosquitoes and Flies found in China. *Lingnan Science Jour.*, 12, Suppl., 23-31.
- LANG, K., 1918. *Monographie der Haptacriden*. Lund: Hakan Ohlssons Boktryckeri. Vol. I, 1-496. Vol. II, 899-1682.
- LEATHERS, A. L., 1923. Ecological Study of Aquatic Midges and some Related Insects with Special Reference to Feeding Habits. *Bull. Bur. Fisheries (U.S.)*, Doc. No. 915, 1-61.
- LEE, D. J., and WOODHILL, A. R., 1944. The Anopheline Mosquitoes of the Australasian Region. *Publ. Univ. Sydney Dept. Zool.*, Monograph No. 2, xii + 1-209.
- LIGER, L., 1902. Sur un flagelle parasite de l'Anopheles maculipennis. *C. R. Soc. Biol.*, 54, 354-356.  
 —— and DUBOIS, O., 1903. Sur les larves d'Anophèles et leurs parasites en Corse. *C. R. Assoc. franc. pour l'avanc. des sci.*, 31<sup>e</sup> sess., 1902, 702-704.
- LESTAGE, J. A., 1928. Remarques sur le Clédon samoëne Hill et ses affinités avec les autres espèces de la région indo-malaise et Australasienne. *Insects of Samoa*, VII. Fasc. 2, 15-47.
- LEVANDER, K. M., 1900. Zur Kenntnis des Lebens in den stehenden Kleingewässern auf den Skäreninseln. *Acta Soc. Fauna Flora fenn.*, 18, (6), 1-107.
- LEVER, R. J. A. W., 1943. Entomological Notes. 5. Mosquitoes in Viti Levu, December 1942 to February 1943. *Agric. J. Fiji*, 14, (1), 16.  
 —— 1943a. Entomological Notes. 4. Further Remarks on the Common Mosquitoes of Viti Levu. *Ibid.*, 14, (2), 42-43.  
 —— 1943b. Entomological Notes. 2. Observations on Culicine Larvae. *Ibid.*, 14, (3), 78-79.  
 —— 1944. Entomological Notes. 5. Terrestrial and Aquatic Crickets. 6. New and Less Common Mosquitoes of Fiji. *Ibid.*, 15, (1), 4-5.
- LEWIS, D. J., 1949. Tracheal Gills in some African Culicine Mosquito Larvae. *Proc. Roy. ent. Soc. Lond.*, (A), 24, 51-55.
- LIRITINGK, M. A., 1919. Synopsis of the Odonate Fauna of the Bismark Archipelago and the Solomon Islands. *Treubia*, 20, (2), 319-374.  
 —— 1953. Notes on some Dragonflies (Odonata) of the Cook Islands. *Proc. Hawaii. ent. Soc.*, 15, (1), 45-49.
- LUNDLAD, O., 1935. Aquatic and Semiaquatic Heteroptera of Tahiti. *H. P. Bishop Museum, Honolulu*, Bull., 113, 121-126.
- MC CANN, E., and SENIOR-WRIGHT, R., 1941. Biological Control of Culicine Mosquitoes by Prawns in a Bengal Coal Mine. *Ind. Med. Gaz.*, 76, (1), 37-38.
- MCKENZIE, A., 1925. Observations on Filariasis, Yaws and Intestinal Helminthic Infections in the Cook Islands with Notes on the Breeding Habits of *Stegomyia pseudoscutellaris*. *Trans. R. Soc. trop. Med. Hyg.*, 19, 138-149.
- MAGAR, T. T., and WORTHINGTON, E. B., 1951. Life in Lakes and Rivers. London: Collins, xi + 1 272.
- MAIDEN, J. H., 1904. The Botany of Funafuti, Ellice Group. *Proc. Linn. Soc. N.S.W.*, 29, 539-556.
- MANALANG, C., 1930. Coccidiosis in Anopheline Mosquitoes. *Philipp. J. Sci.*, 42, 279-282.
- MARKS, E. N., 1917. Studies of Queensland Mosquitoes. Part I. The Aedes (Finlaya) kochi Group with Descriptions of New Species from Queensland, Bougainville, and Fiji. *Qld. Univ. Pprs. Dept. Biol.*, 2, (5), 1-66.  
 —— 1931. Mosquitoes from South-eastern Polynesia. *B. P. Bishop Museum, Honolulu, Occ. Pprs.*, 20, (9), 123-130.  
 —— 1931a. The Vector of Filariasis in Polynesia: a Change in Nomenclature. *Ann. trop. Med. Parasit.*, 25, (1), 137-140.  
 —— 1954. A Review of the *Aedes scutellaris* Subgroup with a Study of Variation in *Aedes pseudoscutellaris* (Theobald) (Diptera: Culicidae). *Bull. Brit. Mus. (Nat. Hist.), Ent.*, 3, (10), 349-414.
- MATTHESON, R., and HINMAN, E. H., 1930. A Seasonal Study of the Plancton of a Spring-fed Chara Pool Versus that of a Temporary or Semi-permanent Woodland Pool in Relation to Mosquito Breeding. *Amer. J. Hyg.*, 11, (1), 174-188.  
 —— 1931. Further Work on Chara spp. and Other Biological Notes on Culicidae. *Ibid.*, 14, 99-108.
- MEYER, E., 1945. *Birds of the Southwest Pacific*. New York: Macmillan. xiv + 1-316.
- METZ, C. W., 1919. Observations on the Food of Anopheles larvae. *U.S. Pub. Hlth. Reps.*, 34, (32), 1783-1791.

- MAILI, L. C., and GILSON, G., 1902. On a New Cricket of Aquatic Habits, Found in Fiji by Professor Gustave Gilson. *Trans. R. ent. Soc. Lond.*, 1902-03, (3), 281-285.
- MICKS, D. W., 1950. The Lethal Effect of the Ciliate, *Vorticella microstoma* Ehrenberg on *Anopheles quadrimaculatus* Larvae. *J. nat. Malar. Soc.*, 9, (3), 256-258.
- MILLS, A. R., 1934. A Health Survey of Futuna Island. *Quart. Bull., South Pacific Commission*, 4, (1), 26-28.
- MOHAN, B. N., 1950. Certain Uncommon Habits of *Culex bitaeniorhynchus* (Type Form). *India J. Malar.*, 4, (2), 167-173.
- MOZLEY, A. 1928. Note on Some Fresh-water Molluscs Inhabiting Temporary Ponds in Western Canada. *The Nautilus*, 42, (1), 19-20.
- MUIRHEAD-THOMPSON, R. C., 1951. *Mosquito Behaviour in Relation to Malaria Transmission and Control in the Tropics*. London: Arnold, viii + 1-219.
- MUNFORD, E. P., 1936. Terrestrial and Fresh-water Fauna of the Marquesas Islands. *Ecology*, 17, (1), 143-157.
- , 1942. Mosquitoes, Malaria and the War in the Pacific. *Science*, 96, (2487), 191-195.
- MURRAY, J., 1911. Rotifera of Some Pacific Islands Collected by the Shackleton Antarctic Expedition (1909). *J. R. micr. Soc.*, 129-143.
- MUSPRATT, J., 1945. Observations on the Larvae of Tree-hole Breeding Culicini (Diptera: Culicidae) and Two of their Parasites. *J. ent. Soc. S. Afr.*, 8, 13-20.
- , 1916. On *Coelonomycetes* fungi Causing High Mortality of *Anopheles gambiae* Larvae in Rhodesia. *Ann. trop. Med. Parasit.*, 10, 1-17.
- NEEDHAM, J. G., and LI YOD, J. T., 1916. The Life of Inland Waters. Ithaca, N.Y.: Comstock, 1-438.
- , and WILLIAMSON, H. V., 1907. *Amer. Nat.*, 41, 477-494.
- , TRAVER, J. R., and YIN-CHI HSU, 1935. *The Biology of Mayflies*. Ithaca, N.Y.: Comstock, xiv + 1-759.
- NENNINGER, U., 1948. Die Perितrichen der Umgebung von Erlangen mit besonderer Berücksichtigung ihrer Wirtschaftlichkeit. *Zool. Jb. (Syst.)*, 77, 169-266.
- NICOL, E. A. T., 1935. The Ecology of a Salt Marsh. *J. Mar. biol. Ass. U.K.*, N.S., 20, (2), 203-261.
- NOLAND, L. E., and FINLEY, II, E., 1931. Studies on the Taxonomy of the Genus *Vorticella*. *Trans. Amer. micr. Soc.*, 50, (2), 81-123.
- NOVY, F. G., MACNEAL, W. J., and TORREY, H. N., 1907. The Trypanosomes of Mosquitoes and Other Insects. *J. infect. Dis.*, 4, 223-276.
- O'CONNOR, F. W., 1923. Researches in the Western Pacific. Res. Mem. Lond. Schl. Trop. Med., IV, iv + 1-57.
- OLIVEIRA, L. DE, ANDRADE, R. M. DE, and NASCIMENTO, R. DO, 1951. Contribuição ao Estudo hidrobiológico dos Cráfados do *Anopheles tarasinae* Goeldi, 1905. *Rev. Brasil. Malar.*, 3, (2), 151-247.
- ORTMANN, A. E., 1891. A Study of the Systematics and Geographical Distribution of the Decipod Family Atyidae Kingsley. *Proc. Acad. nat. Sci. Philad.*, 397-416.
- , 1902. The Geographical Distribution of Freshwater Decapods . . . *Proc. Amer. Phil. Soc.*, 41, (171), 267-400.
- PALINE, R. W., 1934. The Introduction of *Megarhinus* Mosquitoes into Fiji. *Bull. ent. Res.*, 25, (1), 1-32.
- , 1943. *An Introduction to the Mosquitoes of Fiji*. 2nd. Ed., revised by R. J. A. W. Lever. Department of Agriculture, Fiji, Bull. No. 22, 1-35.
- PATON, J. G., 1894. *Letters and Sketches from the New Hebrides*. London: Hodder and Stoughton, xi + 1-322.
- PEARSE, A. S., 1939. *Animal Ecology*. 2nd. Ed. New York: McGraw Hill, xii + 1-642.
- PEL, H. VAN, 1935. Fisheries in the South Pacific. *Quart. Bull. South Pacific Commission*, 5, (3), 2-4.
- , 1955a. Pond Culture of *Tilapia*. *Ibid.*, 5, (3), 30-31.
- PEMBERTON, C. E., 1944. Insects Carried in Transpacific Airplanes. A Review of Quarantine Work Prior to December 7, 1941. *Hawaii Plant. Rec.*, 48, (3), 183-186.
- PENN, G. H., 1947. The Larval Development and Ecology of *Aedes (Stegomyia) scutellaris* (Walker, 1859) in New Guinea. *J. Parasit.*, 33, (1), 43-50.
- , 1949. The Larva and Pupa of *Aedes (Aedimorphus) alboscutellatus* (Diptera, Culicidae). *Nat. Hist. Misc.*, Chicago Acad. Sci., No. 40, 1-4.
- PERRONCITO, E., 1899. Sopra una speciale forma di micosi delle Zanzare. *Boll. della R. Acad. med. Torino*.
- PERRY, W. J., 1945. Notes on the Biology of the Malaria Vector in the New Hebrides-Solomon Islands. *H.Q. Malaria and Epidemic Disease Control South Pacific Area*, Jan., 1945, 1-10.
- , 1945a. Observations on the Bionomics of the Principal Malaria Vector in the New Hebrides-Solomon Islands. *J. nat. Malar. Soc.*, 5, (2), 127-139.

- PERRY, W. J., 1946. Keys to the Larval and Adult Mosquitoes of Espiritu Santo (New Hebrides) with Notes on their Bionomics. *Pan Pacific Ent.*, 22, (1), 9-18.  
 —— 1947. Effectiveness of Disinsectization of Aircraft and Ships in the South Pacific (New Hebrides-Solomon Islands). *Mosquito News*, 7, (3), 109-111.  
 —— 1949. Studies on *Manosiaanthogaster* and its Relation to Filariasis in the South Pacific. *J. Parasit.*, 35, (3), 379-382.  
 —— 1950. The Mosquitoes and Mosquito-borne Diseases on New Caledonia, an Historic Account: 1885-1946. *Am. J. Trop. Med.*, 30, (1), 103-114.  
 —— 1950a. Biological and Cross-breeding Studies on *Aedes hebreus* and *Aedes pernotatus*. *Ann. ent. Soc. Amer.*, 43, (1), 123-136.  
 —— 1950b. Principal Larval and Adult Habitats of *Anopheles farauti* Lav. in the British Solomon Islands. *Mosquito News*, 10, (3), 117-126.  
 POWELL, A. W. B., 1917. *Native Animals of New Zealand*. Auckland: Unity Press, 1-96.  
 PRATT, J. J., HILTRETT, R. H., HARRISON, J. B., and THAYER, L., 1946. Tires as a Factor in the Transportation of Mosquitoes by Ships. *Military Surgeon*, Washington, 99, (6), 783-788.  
 PRECHT, H., 1935. Epizoen der Kieler Bucht. *Nova Acta Leopoldina*, Halle, N.F., 3, (15), 405-174.  
 PRUTIN, H. S., 1928. Some Insect and Other Enemies of Mosquito Larvae. *Ind. J. Med. Res.*, 16, 153-157.  
 PURI, I. M., 1919. Anophelines of the Oriental Region. Chapter 20, pp. 483-505 in *Malaria-ology*, ed. M. F. Boyd. Vol. I. Philadelphia: Saunders.  
 RANNIE, D., 1912. *My Adventures Among South Sea Cannibals*. London: Seeley, Service and Co., 1-314.  
 RAO, C. B., 1953. On the Distribution of Algae in a Group of Six Small Ponds. *J. ecol.*, 41, (1), 62-71.  
 REEVES, W. C., and REDNICK, A., 1951. A Survey of the Mosquitoes of Guam in Two Periods in 1918 and 1949 and its Epidemiological Implications. *Am. J. Trop. Med.*, 31, (5), 633-658.  
 REID, J. A., 1947. Type Specimens of Culicidae Described by Laveran (Diptera: Culicidae). *Proc. Roy. ent. Soc. Lond.*, (B), 16, (7-8), 86-91.  
 ROBERTS, F. H. S., 1948. The Distribution and Seasonal Prevalence of Anopheline Mosquitoes in North Queensland. *Proc. roy. Soc. Qd.*, 59, (2), 93-100.  
 —— and O'SULLIVAN, P. J., 1919. Studies on the Behaviour of Adult Australasian Anophelines. *Bull. ent. Res.*, 39, 159-178.  
 ROSEN, L., 1953. Mosquito Vectors of Human Filariasis in Oceania. Part II (9-16) of *Filariasis in the South Pacific*. Noumea: South Pacific Commission, vii + 1-108.  
 —— 1954. Observations on *Dirofilaria immitis* in French Oceania. *Ann. trop. Med. Parasit.*, 48, (3), 318-328.  
 —— 1954a. Human Filariasis in the Marquesas Islands. *Am. J. Trop. med. Hyg.*, 3, (4), 742-745.  
 —— and ROZENBOOM, L. E., 1954. Morphological Variations of Larvae of the *scutellaris* Group of (Diptera, Culicidae). *Am. J. Trop. med. Hyg.*, 3, (3), 529-538.  
 —— ROZENBOOM, L. E., SWETZ, B. H., and SADIN, A. B., 1954. The Transmission of Dengue by *Aedes polynesiensis* Marks. *Ibid.*, 3, (5), 878-892.  
 ROUGIER, E., 1922. L'eau potable dans les atolls. *Bull. Soc. Etudes océaniennes*, Tahiti, No. 6, 29-32.  
 —— 1926. Moustiques et poissons anti-moustiques. *Bull. Soc. Etudes océaniennes*, Tahiti, No. 13, 65-66.  
 ROZENBOOM, L. E., and KNIGHT, K. L., 1946. The *punctulatus* Complex of *Anopheles* (Diptera: Culicidae). *J. Parasit.*, 32, (2), 99-131.  
 RUSSELL, C. R., 1949. Additions to the Rotatoria of New Zealand. *Trans. roy. Soc. N.Z.*, 77, (3), 351-354.  
 SANDON, H., 1932. *The Food of Protozoa*. Pubs. Faculty of Sci., The Egyptian University, Cairo, No. 1, ii + 1-187.  
 SARS, G. O., 1918. *An Account of the Crustacea of Norway*. Vol. VI. *Copepoda, Cyclopoida*. Bergen: Bergen Museum, xiii + 1-223.  
 SAVILLE-KENT, W., 1880-82. *A Manual of the Infusoria*. London: David Bogue, Vol. I, x + 1 472, Vol. II, 472-913, Vol. III, (51) Plates.  
 SCHEWIAKOFF, W., 1893. Über die geographische Verbreitung der Süßwasser-Protozoen. *Mém. Acad. Sci. St.-Petersb.*, 7, xii, 8, 1-201.  
 SCOTT, W., 1910. *Indiana Acad. Sci.*, 1, 48.  
 SEGUY, E., 1950. *Le biologiste des Diptères*. Encyclopédie Entomologique. Sér. A, XXVI, Paris: Lechevalier, 1-609.  
 SEN, P., 1941. On the Microsporidia Infesting Some Anophelines of India. *J. Malar. Inst. Ind.*, 4, (2), 257-261.

- SENIOR-WHITE, R., 1928. Algae and the Food of Anopheline Larvae. *Ind. J. Med. Res.*, 15, 969-983.
- SEURAT, L. G., 1934. La faune et le peuplement de la Polynésie française. pp. 41-74 in Contribution à l'étude du peuplement zoologique et botanique des îles du Pacifique. *Soc. biogéogr.*, IV. Paris: Lechevalier.
- SHANNON, R. C., 1931. The Environment and Behaviour of Some Brazilian Mosquitoes. *Proc. ent. Soc. Wash.*, 33, 1-27.
- SHIPWYX, B., 1947. Fresh Water Fishes of the Barron River. *North Qld. Nat.*, 15, (84), 5-7.
- SIMMONS, J. S., and ATKEN, T. H. G., 1942. The Anopheline Mosquitoes of the Northern Half of the Western Hemisphere and of the Philippine Islands. *U.S. Army Med. Bull.*, No. 59, 1-213.
- SMITH, G., 1909. Crustacea. Chapters I and III-VII in Vol. IV, *The Cambridge Natural History*. London: Macmillan, xviii + 1-566.
- SMITH, G. M., 1950. *The Fresh-water Algae of the United States*. New York: McGraw-Hill, viii + 1-719. 2nd. Ed.
- SMITH, W. W., 1890. Great Flight of *Culex*, *Tipula*, and *Tetranorium* in New Zealand. *Ent. Mo. Mag.*, 2nd. Ser., 1, 320-322.
- SPEER, A. J., 1927. Compendium of the Parasites of Mosquitoes. *U.S. Hyg. Lab.*, Washington, Bull. 1-6, 1-36.
- STABLER, R. M., 1952. Parasitism of Mosquito Larvae by Mermithidae (Nematoda). *J. Parasit.*, 38, (2), 130-132.
- STEELE, R., 1880. *The New Hebrides and Christian Missions*. London: Nisbet, xv + 1-485.
- STEHR, C. W., and BRANSON, J. W., 1938. An Ecological Study of an Intermittent Stream. *Ecology*, 19, (2), 294-310.
- STEINHAUS, E. A., 1947. *Insect Microbiology*. Ithaca, N.Y.: Comstock, x + 1-763.
- STEPHENSEN, K., 1947. Redescription of *Orchestia anomala* Chevreux, a Terrestrial Amphipod New to Samoa. *Proc. Linn. Soc. Lond.*, 156, (1), 23-26.
- STEPHENS, J., 1930. *The Oligochaeta*. Oxford: Clarendon, xiv + 1-978.
- STONE, A., 1947. A Topotypic Male of *Aedes scutellaris* (Walker) (Diptera, Culicidae). *Proc. ent. Soc. Wash.*, 49, (3), 83.
- — — and BOHART, R. M., 1941. Studies on Mosquitoes from the Philippine Islands and Australasia (Diptera: Culicidae). *Proc. ent. Soc. Wash.*, 46, (8), 205-225.
- — — and PENN, G. II., 1918. A New Subgenus and Two New Species of the Genus *Culex* (Diptera, Culicidae). *Proc. ent. Soc. Wash.*, 50, (3), 109-120.
- — — and ROSEN, L., 1953. A New Species of *Culex* (Diptera, Culicidae) from the Marquesas Islands and the Larvae of *Culex atticeps* Edwards. *Jour. Wash. Acad. Sci.*, 43, 351-358.
- STOUT, J. D., 1951. Some Observations on the Ciliate Fauna of an Experimental Meat Digestion Plant. *Trans. roy. Soc. N.Z.*, 82, (1), 199-211.
- SWEZLEY, O. H., 1930. "Entomology" section in Rep. Comm. Expt. Sta. Hawaii. Sugar. Pt. Asn., 1928-1929, 16-25.
- — — 1931. *Ibid.*, 1929-1930, 23-30.
- — — 1936. The Insect Fauna of Icie (*Freycinetia arborea*) in Hawaii. *Proc. Hawaii. ent. Soc.*, 9, (2), 191-196.
- TAYLOR, F. H., 1934. The Diptera of the Territory of New Guinea -Family Culicidae. *Proc. Linn. Soc. N.S.W.*, 59, 229-236.
- — — 1943. Mosquito Intermediate Hosts of Disease in Australia and New Guinea. *Comm. Aust. Dept. Hlth. Ser. Pub. (Schl. Pub. Hlth. Trop. Med.)*, 4, 1-134.
- THEOBALD, F. V., 1907. *A Monograph of the Culicidae*. London: Brit. Mus. (Nat. Hist.), Vol. IV, xiv + 1-639.
- THIENEMANN, A., 1931. p. 378 in PEARSE, A. S., 1939.
- TIFFANY, L. H., 1951. Ecology of Freshwater Algae. Chapter 15, pp. 293-311 in SMITH, G. M. *Manual of Phycology*. Waltham, Mass.: Chronica Botanica Co.
- TILLYARD, R. J., 1926. *The Insects of Australia and New Zealand*. Sydney: Angus and Robertson. xi + 1-560.
- TOUMANOFF, C., 1941. Note sur quelques insectes aquatiques euliciphages de l'Indochine méridionale. *Rev. med. franc. d'Extrême-Orient*, No. 8, 1051-1060.
- TRAGER, W., 1935. The Culture of Mosquito Larvae Free from Living Microorganisms. *Amer. J. Hyg.*, 22, 18-25.
- TRAVIS, B. V., 1917. Three Species of Flies Predaceous on Mosquito Larvae. *Proc. ent. Soc. Wash.*, 49, (1), 20-21.
- TWINN, C. R., 1931. Observations on Some Aquatic Animal and Plant Enemies of Mosquitoes. *Canad. Ent.*, 63, 51-61.
- VAN THIEL, P. H., 1951. Trematode, Gregarine and Fungus Parasites of *Anopheles* Mosquitoes. *J. Parasit.*, 40, (3), 271-279.

- VAN ZWALUWENBURG, R. H., 1943. The Insects of Canton Island. *Proc. Hawaii. ent. Soc.*, 11, (3), 300-312.  
 ————. 1917. Wir Afternam. *Plantation Health*, Honolulu, 11, (3), 26.  
 WALANDOUW, E. K., 1934. Nematoden als bestrijders van anophelies larven. *Geneesk. Tijdsch. Ned.-Ind.*, 74, 1219-1224.  
 WALKER, A. J., 1938. Fungal Infections of Mosquitoes, Especially of *Anopheles costalis*. *Ann. trop. Med. Parasit.*, 32, 231-244.  
 WALLACE, F. G., 1943. Flagellate Parasites of Mosquitoes with Special Reference to *Crithidia fasciculata* Léger, 1902. *J. Parasit.*, 29, (3), 196-209.  
 WALTON, L. B., 1915. A Review of the Described Species of the Order Euglenoidina Block. *Ohio Biol. Surv.*, Vol. 1, Bull. 4, 343-159.  
 WATERSTON, J. 1918. On the Mosquitoes of Macedonia. *Bull. ent. Res.*, 9, (1), 1-12.  
 WEED, A. C., 1924. Another Factor in Mosquito Control. *Ecology*, 5, 110-111.  
 WEHRLE, E., 1927. Studien über Wasserstoffionenkonzentrationsverhältnisse und Besiedelung an Algenstandorten von Freiburg im Breisgau. *Zeitschr. Bot.*, 19, 209.  
 WELCH, P. S., 1935. Limnology. New York: McGraw-Hill, xiv + 1-171.  
 WENTWORTH, D., 1937. Notes on a Protozoan *Spirostomum* (sp.). *Vict. Nat.*, 54, (3), 42-44.  
 WENYON, C. M., 1926. *Protozoology*. London: Baillière, Tindall and Cox. Vol. I, xvi + 1-778. Vol. II, ix + 779-1563.  
 WESenberg-LUND, C., 1920-21. Contributions to the Biology of the Danish Culicidae. *Mem. Acad. Roy. Sci. Lett. Danemark*, Copenhagen, Sect. Sci., 8th Ser., 7, (1), 1-210.  
 WILST, A. S., 1951. The Canadian Arctic and Sub-Arctic Mosquito Problem. *N.J. Mosquito Extermin. Assn.*, Proc., 38th Ann. Gen. Meeting, 105-110.  
 WIGGLESWORTH, V. B., 1938. The Regulation of Osmotic Pressure and Chloride Concentration in the Haemolymph of Mosquito Larvae. *J. exp. Biol.*, 15, 235-247.  
 WILDER, G. P., 1931. Flora Rarotonga. B. P. Bishop Museum, Honolulu, Bull. 86, 1-111.  
 WILLIAMS, F. X., 1936. Biological Studies in Hawaiian Water-loving Insects. Part I, Coleoptera; Part II, Odonata. *Proc. Hawaii. ent. Soc.*, 9, (2), 235-349.  
 ————. 1943. Biological Studies in Hawaiian Water-loving Insects. Part III, Diptera or Flies—C. Tipulidae and Psychodidae. *Ibid.*, 11, (3), 313-338.  
 ————. 1943a. Mosquitoes and Some Other Noxious Flies that Occur in New Caledonia. *Hawaii. Plant. Rec.*, 47, (4), 205-222.  
 ————. 1944. Biological Studies in Hawaiian Water-loving Insects. Part IV, Lepidoptera or Moths and Butterflies. *Proc. Hawaii. ent. Soc.*, 12, (1), 180-185.  
 WILLIAMSON, K. B., 1928. Mosquito Breeding and Malaria in Relation to the Nitrogen Cycle. *Bull. ent. Res.*, 19, 433-439.  
 ————. 1935. Need for Action in Relation to the Biochemical Investigation of Anopheline Breeding Places and Consequent Resolution by Congress. *Trans. IXth. Congr. P.E.A.T.M.*, 1934, II, 83-87.  
 ————. 1949. Naturalistic Measures of Anopheline Control. Chapter 62, pp. 1360-1384 in *Malariaology*, ed. M. F. Boyd. Vol. II. Philadelphia: Saunders.  
 WOODHILL, A. R., 1915. Observations on the Morphology and Biology of the Sub-species of *Anopheles punctulatus* Dönnit. *Proc. Linn. Soc. N.S.W.*, 70, (5/6), 276-387.  
 ————. 1949. A Note on Experimental Crossing of *Aedes (Stegomyia) scutellaris* scutellaris Walker and *Aedes (Stegomyia) scutellaris katherinensis* Woodhill (Diptera, Culicidae). *Ibid.*, 74, (5/6), 224-226.  
 ————. 1950. Further Notes on Experimental Crossing Within the *Aedes scutellaris* Group of Species (Diptera, Culicidae). *Ibid.*, 75, (5/6), 251-253.  
 ————. 1954. Experimental Crossing of *Aedes (Stegomyia) pseudoscutellaris* Theobald and *Aedes (Stegomyia) polynesiensis* Marks (Diptera, Culicidae). *Ibid.*, 79, (1/2), 19-20.  
 YAMAGUTI, S., and LACASSE, W. J., 1950. *Mosquito Fauna of Guam*. 207th. Malaria Survey Detachment, A.P.O. 301, Office of the Surgeon, U.S. Army, A.P.O. 343, 1-101.  
 ZIMMERMAN, E. C., 1942. Distribution and Origin of Some Eastern Oceanic Insects. *Amer. Nat.*, 76, (764), 280-307.

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