Dr. J. Parkinson

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Technical Paper No. 148

EPIDEMIOLOGY OF FILARIASIS IN THE SOUTH PACIFIC

(avec un résumé en Français)

M. O. T. IYENGAR

NOUMEA, NEW CALEDONIA
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...ic Commission Technical Paper No. 148 - EPIDEMIOLOGY OF FILARIASIS IN THE SOUTH PACIFIC, by M.O.T. Iyengar

E R R A T A

Page	Line	
7	22	for "this last" read "the last"
19	27	for "favourable the" read "favourable for"
23	29	for "vectof" read "vector"
36	29	for "habitation" read "habitations"
40	30	for "that the" read "that in"
51	21	for "factors" read "factor"
52	4 from bottom	for "know" read "known"
61	27	for "secondly" read "secondarily"
69	23	for "person" read "persons"
69	29	for "northernly" read "northerly"
72	5	for "brought" read "brought out"
75	3 from bottom	for "Oenata" read "Oneata"
82	17 from bottom	for "Eight to" read "Eight of"
93	5 from bottom	for "many of" read "many on"
99	24	for "It mentioned" read "It was mentioned"
114	13 from bottom	for "fells" read "feels"
122	Table 18, line 2	for "Microfilaria rate" read "Elephantiasis rate"
123	last line	for "villages" read "village"
128	18	for "islest" read "islets"
131	2	for "Maniki" read "Manihiki"
143	21 from bottom	for "particulièment" read "particulièrement"
144	4 from bottom	for "physiological" read "physiographical"
145	19	for "natural rate" read "natural infection rate"
147	21	for "Raroi" read "Raroia"
151	2 from bottom	for "coefficient of" read "coefficient of correlation"
156	9 from bottom	for "moutainous" read "mountainous"
165	4 from bottom	for "nee" read "needed"
165	2 from bottom	for "mosquito" read "mosquito during"
168	15	for "trival" read "tribal"
174	16	for "(Stegomya)" read "(Stegomyia)"

South Pacific Commission
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South Pacific Commission
Noumea, New Caledonia
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THE SOUTH PACIFIC COMMISSION

The South Pacific Commission is an advisory and consultative body set up in 1947 by the six Governments then responsible for the administration of island territories in the South Pacific region (Australia, France, the Netherlands, New Zealand, the United Kingdom and the United States of America). Participation by the Netherlands Government ceased at the end of 1962. The Independent State of Western Samoa was admitted as a participating Government in October, 1964.

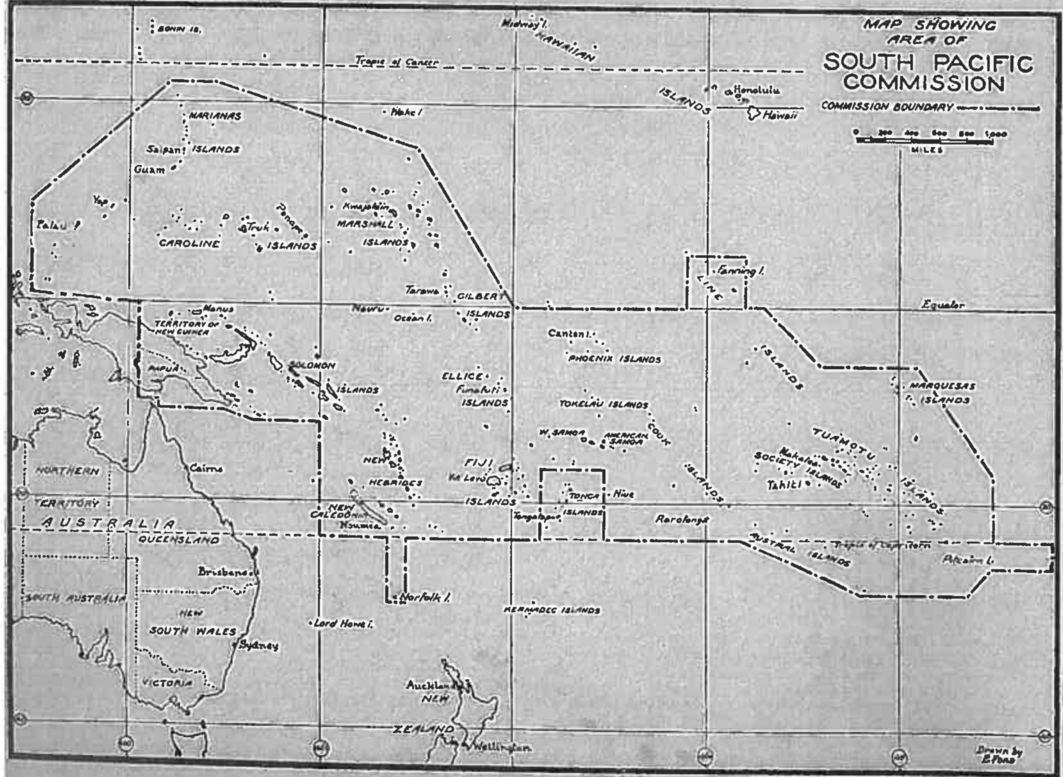
The Commission's purpose is to advise the participating Governments on ways of improving the well-being of the people of the Pacific island territories. It is concerned with health, economic and social matters. Its headquarters are at Nouméa, New Caledonia.

The Commission consists of not more than twelve Commissioners, two from each Government. It normally holds one session each year. There are two auxiliary bodies, the Research Council and the South Pacific Conference.

The Research Council has normally met once a year. Members of the Research Council are appointed by the Commission. The chief function of the Research Council is to advise the Commission on the work programme.

The South Pacific Conference, which meets at intervals not exceeding three years, consists of delegates from the local inhabitants of the territories, who may be accompanied by advisers. The first Conference was held in Fiji in April, 1950. The second Conference was held at Commission headquarters in April, 1953, the third in Fiji in April-May, 1956, the fourth in New Britain in April-May, 1959, and the fifth in Pago Pago, American Samoa, in July, 1962. The sixth Conference was held at Lae in July, 1965.

The principal officers of the Commission are: Secretary-General, Mr. W. D. Forsyth; Executive Officer for Social Development, Dr. Richard Seddon; Executive Officer for Economic Development, Mr. William Granger; Executive Officer for Health, Dr. Guy Loison. The powers and functions of the Deputy Chairman, Research Council, are exercised by the Secretary-General.



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PREFACE

Five years have already elapsed since Dr. M.O.T. Iyengar, who had been working on the Filariasis Project since 1953, left the South Pacific Commission. Back in India, he has continued to work on the notes he took in the course of his research work in our region. The Commission is particularly happy to add the present volume on the Epidemiology of Filariasis to the list of its publications on filariasis in the South Pacific. Of the thirty or so works already published, Dr. Iyengar has himself written more than twenty. This particular volume, published just prior to an inter-regional Seminar in Manila under the auspices of the World Health Organization, is very timely.

It will be recalled that the first Filariasis Conference was organized in Tahiti by the South Pacific Commission in 1951. That conference was convened to define the problems to which endemic filariasis in the region gave rise, to decide on the research to be undertaken, and to suggest remedial action. The conference issued fifty-six recommendations which provided a foundation for Dr. Iyengar's labours. The latter submitted the fruits of his research to a panel of experts meeting in Noumea in 1959. This panel was then apprised of Dr. Iyengar's intention to write a work on the epidemiology of filariasis and gave its approval to this project.

The Memoir we now present is the fruit of laboratory research and of investigations - entomological, parasitological and epidemiological - pursued in several Pacific island groups.

Endemic filariasis differs considerably from place to place. There is agreement, of course, that virus reservoirs should be eliminated and the chain of transmission interrupted. Clearly, however, action against the vectors will have to vary considerably. Any action undertaken without consideration being given to the biology of each species of mosquito and in particular to the differences between one breeding site and another (degree of exposure to the sun, salinity, extent of organic contamination, etc.) is foredoomed to failure. Whence the need for an entomological survey first of all, to be undertaken by a specialist.

But there are differences which have to be taken into account within one and the same group of islands, within one island, and even within one valley. The chances of mosquito meeting man, the density of the vectors, frequently depend on social and economic factors. A great many vector mosquitoes breeding close to an infected community will provide ideal conditions for an endemic to persist or to become more extensive.

Few South Pacific Health Departments have a budget which would enable them to exterminate all vectors and do away with infection, but some already look forward to the day when the disease will be eradicated. *In the meantime the chances of transmitting* the disease will be reduced by vigorous action against vector mosquitoes in the light of detailed information about the bionomics of the mosquitoes, which information will need to be supplemented by familiarity with the customs, beliefs, psychology, level of education, and so on, of the local people.

The South Pacific Commission is leaving the responsibility of carrying on research into filariasis to specialist bodies. But its work programme nevertheless provides for two new types of activity designed to supplement these inquiries in a practical way, namely, environmental sanitation and public health education. To this end, a sanitary engineer and two health educators are available to assist territories. Furthermore, in its programme of assistance for research, the Commission has two headings which derive directly from its former project on mosquito-borne diseases, namely, action against rats (which help to create breeding sites for mosquitoes) and biological action against disease-carrying insects.

However, Recommendation No. 51 of the first Filariasis Conference (Tahiti, 1951) still holds good. It requested:-

> " That all presently available measures be adequately applied for the control of the disease where warranted in the South Pacific, pending the accumulation of more specific data concerning the relative effectiveness of these and other methods under varying conditions of transmission. "

This publication will provide a scientific basis for anti-filariasis campaigns which governments may intend to undertake in their territories.

Guy Loison, M.D., M.P.H.
Executive Officer for Health,
South Pacific Commission.

Noumea,
New Caledonia.
1965

Original text: French

R E S U M E

La filariose endémique dans le Pacifique Sud est transmise par deux formes biologiques de Wuchereria bancrofti: la forme périodique et la forme apériodique. La première est transmise par certaines espèces de moustiques qui piquent pendant la nuit et ses microfilaires présentent une périodicité nocturne caractéristique dans la circulation périphérique de leur hôte humain. Par contre, les hôtes intermédiaires de W. bancrofti apériodique sont, de préférence, certaines espèces de moustiques qui piquent le jour, et leurs microfilaires ne présentent pas de périodicité nocturne, mais circulent dans le sang périphérique aussi bien de jour que de nuit. Il n'y a, entre les deux formes, aucune distinction morphologique, et rien ne laisse supposer que leur pathogénicité respective soit différente.

Par contre, leur répartition géographique n'est pas la même. En effet, on trouve la filaire de Bancroft périodique dans le secteur bordé par la Micronésie au nord et certaines îles mélanésiennes à l'ouest, alors que W. bancrofti apériodique se trouve dans la partie orientale du Pacifique Sud (des îles Fidji et Ellice jusqu'aux limites orientales de la région), ainsi qu'en Nouvelle-Calédonie et aux Iles Loyauté au sud-ouest. Quant aux moustiques vecteurs, un grand nombre d'espèces, à bionomie très variée, transmettent la filariose dans différentes parties du Pacifique Sud.

Du point de vue épidémiologique, on distingue les quatre zones suivantes, en fonction, d'une part, de la forme et de la souche de W. bancrofti présent, d'autre part, des vecteurs:

1. la zone micronésienne, où W. bancrofti appartient à une souche du type périodique analogue à la souche asiatique, et est transmis par Culex fatigans;

2. la zone papoue, où la souche papoue de W. bancrofti, périodique, est principalement transmise par trois anophèles du groupe Anopheles punctulatus: Anopheles farauti, A. koliensis et A. punctulatus.

3. la zone polynésienne, où W. bancrofti apériodique est transmis par une ou plusieurs des cinq espèces du groupe Aedes (Stegomyia) scutellaris, à savoir: Aedes polynesiensis, A. pseudoscutellaris, A. tongae, A. rotumae et A. cooki;

4. la zone néo-calédonienne où W. bancrofti apériodique est transmis par Aedes (Ochlerotatus) vigilax.

Chacune de ces quatre zones est étudiée en détail en ce qui concerne la distribution et la fréquence de l'infestation filarienne et de la filariose clinique, des vecteurs et de leur bionomie, ainsi que des facteurs qui influent sur l'endémie filarienne.

Considérant le Pacifique Sud dans son ensemble, la fréquence de l'infestation filarienne et de la filariose clinique varie considérablement d'une région habitée à l'autre. En effet, selon le degré d'exposition des habitants à l'infestation, il peut y avoir soit absence totale de l'endémie, soit infestation asymptomatique, soit, au contraire, une incidence importante de filariose clinique parmi la population.

La transmission de la filariose repose sur deux facteurs: 1. la densité de la population de moustiques vecteurs en contact permanent avec la population humaine; 2. la proximité des gîtes de reproduction des moustiques par rapport aux habitations. En effet, cette transmission n'est possible que lorsque les moustiques sont suffisamment abondants pour supporter une réduction éventuelle de leur nombre pendant la période d'incubation extrinsèque du parasite. Il faut, d'autre part, que le vecteur soit au contact permanent de l'homme pour que les moustiques soient parasités à partir du réservoir humain et qu'ils parasitent à leur tour l'homme une fois la filaire arrivée à son stade infestant. Lorsque la densité du vecteur est faible ou que ses contacts avec l'homme sont irréguliers, il y a peu de chances que la maladie soit transmise.

Les oeufs arrivent à maturation après chaque repas de sang; or, du fait que le moustique femelle est obligé de pondre dans un gîte de reproduction convenant à l'espèce intéressée, la transmission de l'infestation filarienne n'est possible que si la distance entre ce gîte et les habitations humaines ne dépasse pas le rayon de vol d'une femelle gravide, porteuse de larves de W. bancrofti. Ce rayon de vol varie d'ailleurs selon les espèces; minimum chez Aedes polynesiensis, il atteint son maximum chez Aedes vigilax.

L'intensité de la transmission en une région donnée - qui détermine l'endémicité locale - dépend donc de la conjonction de ces deux facteurs, à savoir une densité élevée de moustiques vecteurs en contact continu avec l'homme, et, d'autre part, la proximité (mesurée en rayon de vol de l'espèce vectrice) des gîtes de reproduction par rapport aux habitations humaines.

Lorsqu'il n'y a pas de gîtes de reproduction à proximité d'un village, l'endémie filarienne en est absente, même s'il y a un afflux considérable de moustiques venant de gîtes de reproduction éloignés du village. De même, si la densité de moustiques vecteurs est peu élevée, l'endémie filarienne est rare même s'il existe des gîtes de reproduction à proximité du village. Si les habitants d'un village où ces deux conditions sont réunies se trouvent exposés de façon intermittente à l'infestation en brousse ou dans des plantations où les moustiques vecteurs sont très nombreux, ils seront parasités mais, n'étant pas exposés à l'infestation de façon intensive et continue, on ne trouvera chez eux pratiquement aucun cas de filariose clinique. C'est le cas des îles Tokelau et Tuamotu ainsi que des atolls de la partie nord des îles Cook. De même lorsque les gîtes de reproduction sont suffisamment proches des habitations pour rendre la transmission possible, mais pas suffisamment pour permettre qu'elle soit intensive, il y aura infestation filarienne,

mais la filariose clinique sera rare. C'est le cas de la plupart des foyers endémiques des îles Salomon, des Nouvelles-Hébrides et de la Nouvelle-Calédonie et de bien de ceux de Nouvelle-Guinée. Même situation encore là où les gîtes de reproduction sont proches des habitations mais où les moustiques vecteurs, tout en étant suffisamment nombreux pour parasiter l'homme, ne sont pas en nombre suffisant pour que ce parasitage soit intensif. C'est le cas des foyers endémiques des Iles Carolines et Australes.

Dans les cas énumérés ci-dessus, les conditions locales sont telles que l'infestation ne peut être réalisée de façon intensive si bien que, même si le parasite est présent dans certaines collectivités, les manifestations cliniques de filariose sont absentes ou fort rares. Elles ne s'observeront en grand nombre que dans les régions où existent, à proximité des agglomérations, des gîtes de reproduction situés à une distance sensiblement inférieure au rayon de vol du vecteur local, et où celui-ci se reproduit en nombre suffisant pour maintenir localement une densité élevée de moustiques. Dans ces conditions, l'homme est exposé de façon continue à une infestation intensive, l'hyperinfestation est fréquente et le pourcentage de cas de filariose clinique est important. Autrement dit, plus la densité du vecteur est élevée et plus les gîtes de reproduction sont proches des habitations, plus il y aura de cas de filariose clinique dans la collectivité.

Des mesures ayant eu pour résultat direct ou indirect de réduire la reproduction des moustiques aux alentours des villages, ou d'augmenter la distance entre les habitations et les gîtes de reproduction du vecteur, ont entraîné une diminution sensible du nombre de filarioses cliniques dans des régions où la maladie sévissait couramment autrefois. Ces observations montrent que, vu leur influence sur l'aire et l'intensité de la reproduction des moustiques vecteurs, ce sont les conditions d'hygiène du milieu qui déterminent la prévalence de la filariose dans les villages. Cette conclusion permet d'envisager d'utiles mesures de santé publique.

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* * *

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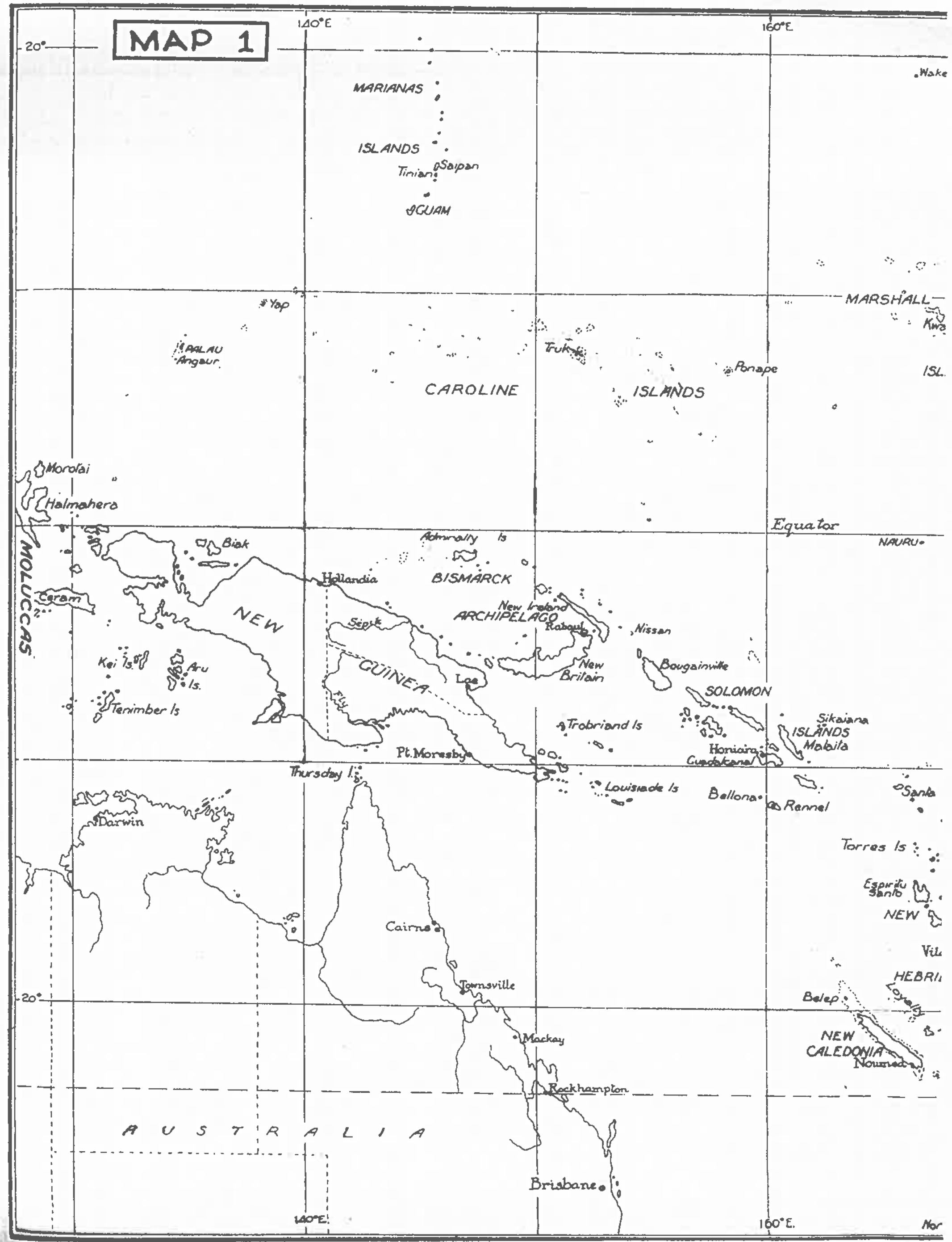
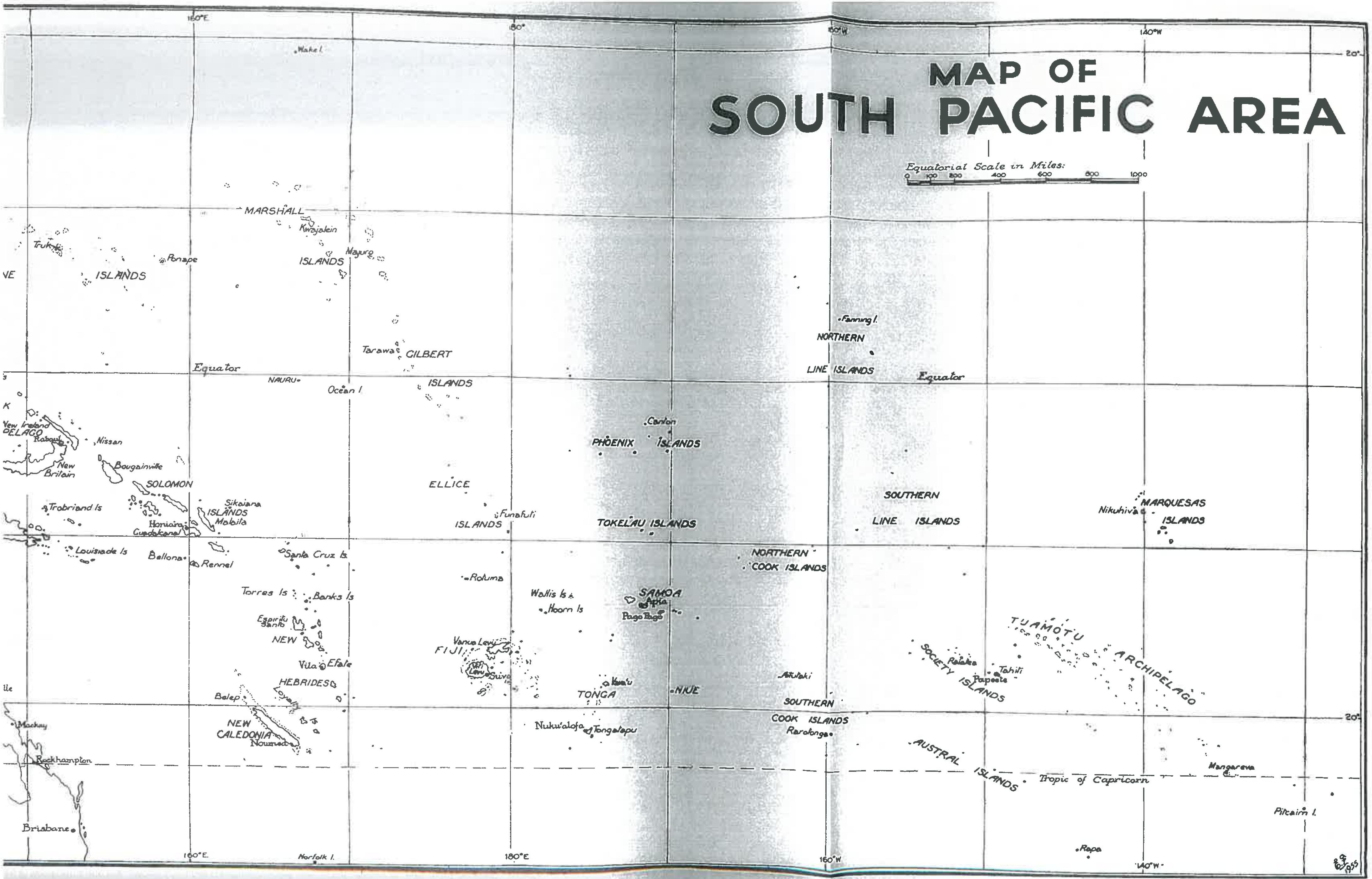


MAP 1
140°E
160°E
20°
MARIANAS ISLANDS
Saipan
Tinian
GUAM
Yap
PALAU
Angaur
CAROLINE ISLANDS
Truk
Ponape
MARSHALL
Wake
Morotai
Halmahera
MOLUCCAS
Ceram
Biak
Kei Is
Aru Is.
Tenimber Is
NEW GUINEA
Hollandia
Sepik
Fly
Lae
Pt. Moresby
Admiralty Is
BISMARCK ARCHIPELAGO
New Ireland
Rabaul
New Britain
Nissan
Bougainville
SOLOMON ISLANDS
Sikaiana
Malaita
Honiara
Guadalcanal
Trobriand Is
Louisiade Is
Bellona
Rennel
Equator
NAURU
Santa
Torres Is
Espiritu Santo
NEW HEBRI
Thursday I.
Darwin
Cairns
Townsville
Mackay
Rockhampton
Brisbane
A U S T R A L I A
Belep
NEW CALEDONIA
Noumea
140°E.
160°E.


MAP OF
SOUTH PACIFIC AREA
Equatorial Scale in Miles:
0 100 200 400 600 800 1000
160°E
180°
160°W
140°W
20°
Equator
Tropic of Capricorn
Wake I.
MARSHALL ISLANDS
Kwajalein
Majuro
Truk
Ponape
ISLANDS
Tarawa
GILBERT ISLANDS
NAURU
Ocean I.
New Ireland
Rabaul
Nissan
New Britain
Bougainville
SOLOMON ISLANDS
Sikaiana
Malaita
Honiara
Guadalcanal
Trobriand Is
Louisiade Is
Bellona
Rennel
Santa Cruz Is
Torres Is
Banks Is
Espiritu Santo
NEW HEBRIDES
Vila
Efate
Belep
Loyalty
NEW CALEDONIA
Noumea
Mackay
Rockhampton
Brisbane
Norfolk I.
ELLICE ISLANDS
Funafuti
Rotuma
FIJI
Vanua Levu
Suva
Wallis Is
Hoorn Is
TONGA
Nuku'alofa
Tongatapu
PHOENIX ISLANDS
Canton
TOKELAU ISLANDS
SAMOA
Apia
Pago Pago
NIUE
NORTHERN COOK ISLANDS
Aitutaki
SOUTHERN COOK ISLANDS
Rarotonga
Fanning I.
NORTHERN LINE ISLANDS
SOUTHERN LINE ISLANDS
MARQUESAS ISLANDS
Nikuhiva
TUAMOTU ARCHIPELAGO
SOCIETY ISLANDS
Raiatea
Tahiti
Papeete
AUSTRAL ISLANDS
Rapa
Mangareva
Pitcairn I.
1955

I. INTRODUCTORY

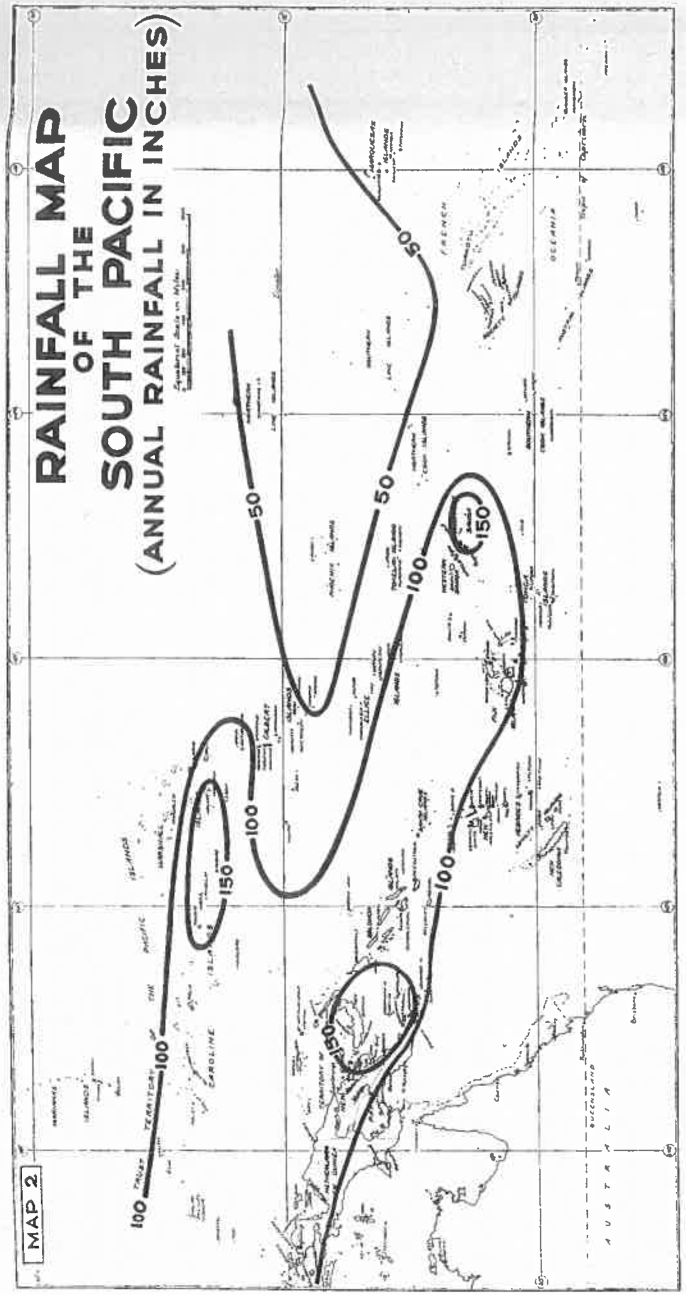
This work is an attempt to bring together under one cover as much as possible of the available information on the epidemiology of filariasis in the South Pacific region. Two races of Wuchereria bancrofti occur here, the periodic and the non-periodic, with distinct ranges of geographical distribution. Within the range of distribution of each of these two races of W. bancrofti, two separate zones can be differentiated on the basis of the mosquito vectors involved in the transmission. The island groups constituting these four epidemiological zones are discussed individually, with reference to their topography, population, incidence of filarial infection and of filarial disease, the vectors and their bionomics, and the local factors which determine filarial endemicity. In the concluding chapter the broad aspects of the epidemiology of filariasis in the South Pacific are summarized and discussed.

II. DESCRIPTION OF THE AREA

(1) Physical features

The South Pacific region, as here demarcated, extends from New Guinea on the west to Marquesas and Tuamotu Islands on the east, and from Mariana Islands on the north to New Caledonia and Austral Islands on the south (Map 1). It lies between latitudes 21° N. and 28° S., and between longitudes 129° E. and 130° W., and includes the territories falling within the scope of the South Pacific Commission and, in addition, the Kingdom of Tonga which, although outside the area of the Commission, forms part of this geographical region. The number of islands scattered over this vast expanse of the Pacific Ocean, 6000 miles from east to west and 3000 miles from north to south, has been estimated at about 10,000 and their total land area at about 380,000 square miles. The islands vary considerably in size and in topography, from the huge continental island of New Guinea (area 320,000 square miles) with its high mountains rising to peaks of 15,000 feet or more, some of which are snow-clad, to tiny islets barely a few acres in extent and just a few feet above mean sea level. The islands of the South•Pacific may broadly be classified under three heads: (1) high islands of volcanic origin with a mountainous interior and skirted by a narrow coastal plain; (2) low atoll islands; and (3) raised coral islands; islands of the last category are few in number.

In the western part of the South Pacific is a chain of large high islands, - New Guinea. New Britain, New Ireland, Solomon Islands, New Hebrides and New Caledonia; these together constitute more than 95 per cent of the total land of the South Pacific. In the north is Micronesia, an assemblage of about 2,400 small islands scattered over a great area of the warmer part of the Western Pacific Ocean; they form four chains of islands, the Caroline Islands, the Mariana Islands, the Marshall Islands



and the Gilbert Islands. Extending eastwards from Fiji at the centre of South Pacific, to its extreme easterly limit are numerous groups of small islands scattered over a wide expanse of the ocean - Ellice Islands, Tonga, Wallis Islands, Samoa, Tokelau Islands, Cook Islands, Phoenix and Line Islands, Society Islands, Austral Islands, Tuamotu Archipelago, Marquesas Islands and Pitcairn.

(2) Climate

Practically the whole of the South Pacific region (with the exception of a few small islands, like Raivavae, Rapa and Pitcairn) falls within the tropics. The climate may broadly be described as "tropical-oceanic", characterized by rather uniform warm temperatures, fair to heavy rainfall and high atmospheric humidity. Temperatures on all but the very large islands vary little during the year. A pronounced winter is lacking. There is no appreciable difference between the average temperatures of the warmest and the coldest months. The average temperature in the coldest months is seldom less than 78° F., or in the hottest month more than 82° F. The areas falling within the subtropical zone (to the south of latitude 20° S.), as for example New Caledonia, Loyalty Islands, Southern Tonga, Southern Cook Islands, Austral Islands and Gambiers experience a distinct drop in temperature during winter. Many of the larger islands rise to considerable heights and have fair-sized areas where the temperature is profoundly modified. By and large, the islands of the South Pacific have uniform warm temperatures with little diurnal or seasonal variations. Summer is mostly the season of heavy rainfall and maximum atmospheric humidity. Annual rainfall varies considerably with the different types of islands and in different parts of the region. High islands receive much rain from the prevailing winds, and in such islands rainfall is heavier on the windward than on the leeward side. Most of the low islands, as for example the coral atolls, derive little rainfall from the trade winds; on such islands rainfall is low and unreliable, and drought occurs frequently.

Heavy rainfall, 100 to 150 inches annually, occurs along the equator in the western part of the region, namely New Guinea and Caroline Islands. Two arms of this belt of heavy rainfall extend eastwards, into Marshall Islands on the north, and into Solomon Islands, Fiji and Samoa on the south (Map 2). Within this extensive wet belt, rainfall is heavy during all months of the year and there is no distinct dry season.

Outside of this wet zone, rainfall is less, generally below 80 inches in the year, as for example New Hebrides and New Caledonia on the south; Cook Islands, Niue and Society Islands on the east; and Mariana Islands and Northern Marshalls on the north. In these areas, rainfall is to some extent seasonal, being heavier during summer and early autumn than during the other seasons. A remarkable feature of the South Pacific is the intrusion of a wedge of very low rainfall - less than 50 inches in the year - extending westwards along the equator, to include the Line and Phoenix Islands and the Southern Gilbert Islands. Within this arid zone, rainfall is very low and uncertain; drought occurs frequently and even the supply of drinking water is often short. On some of the islands within this dry equatorial belt, conditions are so arid that vegetation is stunted and even the coconut palm does not thrive.

(3) Population

The indigenous population of the South Pacific is made up of three major races, the Melanesian, the Micronesian and the Polynesian, each of which has a more or less well-defined range of geographical distribution. The largest of these races, the Melanesian, constituting 87 per cent of the total population of the South Pacific, has a range of distribution covering the western and south-western part of the region, namely New Guinea, Bismarck Archipelago, Solomon Islands, New Hebrides, New Caledonia, Loyalty Islands and Fiji. The Micronesian race, forming 4 per cent of the total population, inhabits the island groups in the northern and north-western parts of the region, namely Mariana Islands, Caroline Islands, Marshall Islands, Gilbert Islands, Ocean and Nauru. The Polynesian race (8 per cent of the total population) inhabits the eastern section of the region extending eastwards from Rotuma, Ellice Islands and Tonga to Marquesas and Tuamotus. In the areas bordering on the ranges of distribution of these races, there occurs some mixing of the races. In Fiji, Loyalty Islands and parts of New Caledonia, there is an admixture of the Melanesian race with the Polynesian. In Marshall Islands there is a blending of the Micronesian race with the Polynesian.

The Phoenix and Line Islands do not have any populations indigenous to these islands; they are at present inhabited by imported labour, principally Micronesians from the Gilbert Islands recruited for work on the coconut plantations for short terms of two years or so.

The total population of the South Pacific is estimated at about 3.5 million. The populations of the different islands and island groups are furnished in Table 1, as also their areas and population densities. An essential feature of the South Pacific communities is that they are not concentrated in many large urban areas. The vast majority of the people live in villages or in small rural settlements. Urban concentrations of population are few, as for example Suva (Fiji), Noumea (New Caledonia), Guam (Marianas), and Papeete (Tahiti). There are several smaller townships of a quasi-urban character. On the phosphate-bearing islands, Nauru, Ocean and Makatea, large labour forces engaged on working the phosphate deposits are concentrated to compact labour settlements. Other than these, the populations are typically rural.

The density of population in the different islands varies considerably. The larger islands in the western part of the region have extremely low population densities, 10 per square mile or less, even including the populations of the townships. New Guinea has a population density of 7.2 per square mile; Bismarck Archipelago, 8.2; Solomon Islands, 10.6; New Hebrides, 8.6; and New Caledonia, 9.0. In comparison with the low population densities of the larger islands in the western part of the region, the small islands in the eastern section have appreciably higher densities of population.

TABLE 1.

	Area in square miles	Population	Population density per sq. m.
(a) Melanesian Islands:			
New Guinea:			
Western New Guinea	160,000	709,600	
Eastern New Guinea	160,240	1,596,400	
Total	320,240	2,306,000	7.2
Bismarck Archipelago:			
New Britain	14,600	102,200	
New Ireland	3,800	37,700	
Admiralty Islands	800	16,800	
Total	19,200	156,700	8.2
Solomon Islands:			
Bougainville	4,100	51,800	
Other Islands	11,500	114,100	
Total	15,600	165,900	10.6
New Hebrides	5,700	49,000	8.6
New Caledonia	6,281	56,800	9.0
Loyalty Islands	800	13,900	17.4
Fiji Islands	7,037	369,900	52.6
(b) Micronesian Islands:			
Mariana Islands:			
Guam	206	36,000	174.8
Saipan & Rota	247	8,200	33.6
Total	453	44,200	97.6
Caroline Islands	600	48,400	80.7
Marshall Islands	66	13,900	210.6
Gilbert Islands	114	33,000	289.5
Nauru	8½	4,300	506.2
Ocean Island	2½	2,500	1000.0

(Table 1 contd)

	Area in square miles	Population	Population density per sq. m.
(c) Polynesian Islands:			
Rotuma	18	4,400	244.4
Ellice Islands	10	5,000	500.0
Wallis Islands	24	6,500	270.8
Hoorn Islands	34	2,800	84.7
Tokelau Islands	4	1,600	400.0
Tonga	259	58,400	225.5
Western Samoa	1,133	100,500	88.7
Eastern Samoa	77	21,000	272.7
Niue	100	4,700	47.0
Cook Islands	89	16,900	190.0
Society Islands	636	54,700	86.0
Makatea	10	2,300	230.0
Tuamotu & Gambier Islands (excluding Makatea)	343	8,200	24.0
Austral Islands	63	4,000	63.5
Marquesas Islands	492	3,900	8.0
Pitcairn Island	2	150	75.0
(d) Islands without indigenous populations:			
Line Islands	238	900	3.8
Phoenix Islands	11	1,200	109.1
Total for South Pacific area	379,645	3,561,650	

Many of the islands in the eastern section, although with a purely agricultural economy, have high population densities, as for example Ellice Islands (500 per square mile), Tokelau Islands (400), Gilbert Islands (289), Rotuma (244), Eastern Samoa (272), Marshall Islands (210), Cook Islands (190), and Wallis Islands (270).

The economy of the people of the South Pacific is essentially agricultural. Their staple food consists of taro, yam, banana, sweet potato, breadfruit and coconut, all of which are extensively cultivated. Ordinarily, sufficient food is grown on these islands to meet the requirements of the population, except perhaps on some of the islands within the arid region of the central equatorial zone.

It may be of interest to summarize what is known of the origin and affinities of the peoples of the South Pacific. According to well-recognized authorities on the subject, they are derived from different stocks that successively migrated eastwards from South-east Asia through Malaysia into the South Pacific over a long period of time commencing probably from the Fourth Glacial Epoch. Several such migrations occurred in the past. According to Oliver (1951)*, the Ainoids moved from Malaysia to New Guinea and neighbouring islands and thence to Australia during the Fourth Glacial Epoch. This race had a light coloured skin, wavy hair and bodies hirsute. The Veddoids with physical affinities to the Veddas of India, came in after the Ainoids and followed the same route. During this last glacial period the Negritos, a short statured, dark skinned, frizzly haired Negroids, ultimately related to the short-statured Negritos of Africa, pushed out of South-east Asia; they occupied parts of Malaysia and then crossed over to New Guinea and neighbouring islands and thence to Australia. There is some difference of opinion among the authorities as to the sequence of these migrations. Some authorities hold the view that the Negroids were the first to migrate into the South Pacific and that they were followed later by the Ainoids and then by the Veddoids; others consider that the Ainoids were the first to arrive.

These three races blended in varying proportions and spread out from New Guinea into Bismarck Archipelago, Solomon Islands, New Hebrides, New Caledonia and Fiji, as also into Australia. In the different areas colonized, one or the other of the three racial characteristics predominates. The Negrito element is dominant practically throughout Melanesia. Negrito pygmies are still to be found on the hills of New Guinea and Bougainville (Solomon Islands), as also in the tropical forests of Queensland and in Tasmania. The Ainoid element is strong in New Caledonia and South Australia. The Veddoid element dominates in Southern Papua and in North Australia.

During the neolithic period the Proto-Malays, a composite of Caucasian and Mongoloid races, with light brown skin, black hair straight or wavy, and broad cheek bones, pressed into Malaysia and thence to New Guinea and the islands nearby. During the pre-Christian period the Pre-Tangaroans

*Oliver, D.L. 1951 The Pacific Islands.

migrated eastwards through Melanesia into Polynesia. The Tangaroans migrated eastwards during the Christian era spreading out from New Guinea into Polynesia, while others travelled by the Micronesian route through the Carolines, Marshalls, Gilberts and Ellice Islands. A second stream of Tangaroans came from Malaysia as an organised movement by way of Micronesia through the Gilberts, Ellices and farther east into Polynesia. These were the ancestors of the Polynesians of today. It would appear that the major part of the Tangaroan migrations into Polynesia followed the Micronesian route.

The Micronesian Islands were subsequently colonized by hybrid Indonesian racial types. These ancestors of the Micronesians settled in the Marianas, Carolines, Marshalls and Gilberts, and became differentiated from the Polynesians. They made several attempts to migrate eastwards from Gilbert Islands into Ellice Islands and other Polynesian islands farther east. All these attempts to extend their area of colonization were met with fierce opposition from the Polynesians; the Micronesians were driven back to the Gilbert Islands which form the easterly limit of the present range of distribution of the Micronesian race. Within the range of distribution of the Micronesian race, there are some differences in physical features; in the Mariana Islands, the Malayan element is dominant; in the eastern part, namely the Marshall Islands, the Polynesian element is dominant.

After the three South Pacific races became differentiated, there have been several intra-Pacific migrations, as for example the Micronesian spill-over into Nuguria (Bismarck Archipelago), the Polynesian spill-over from Samoa into Rennell, Bellona, Sikaiana and Ontong Java (Solomon Islands), and the Polynesian migrations from Wallis Islands and Samoa into Loyalty Islands and New Caledonia.

III. FILARIAL INFECTION IN THE SOUTH PACIFIC

(1) Types of filarial infection

Endemic filarial infection has a wide distribution in the South Pacific and consists of one or the other of the two races of *Wuchereria bancrofti*, - the periodic race and the non-periodic race. The periodic race is characterized by a well-marked nocturnal periodicity of its microfilaria, and is adapted for transmission by certain species of night-biting mosquitoes. The non-periodic race of *W. bancrofti*, on the other hand, exhibits no microfilarial periodicity, and finds its most favourable intermediate hosts in certain species of day-biting mosquitoes. As will be seen later, these two races have distinct ranges of geographical distribution, and do not occur in any area coendemically.

Other than the two races of *W. bancrofti*, no other type of filarial infection of man is known to occur in the South Pacific. The reported finding of *Filaria demarquayi* from New Guinea (Manson 1897) and that of

Filaria perstans from Lau in Fiji (Lynch 1905) have not been confirmed by any of the later workers; presumably these records were based on wrong identifications.

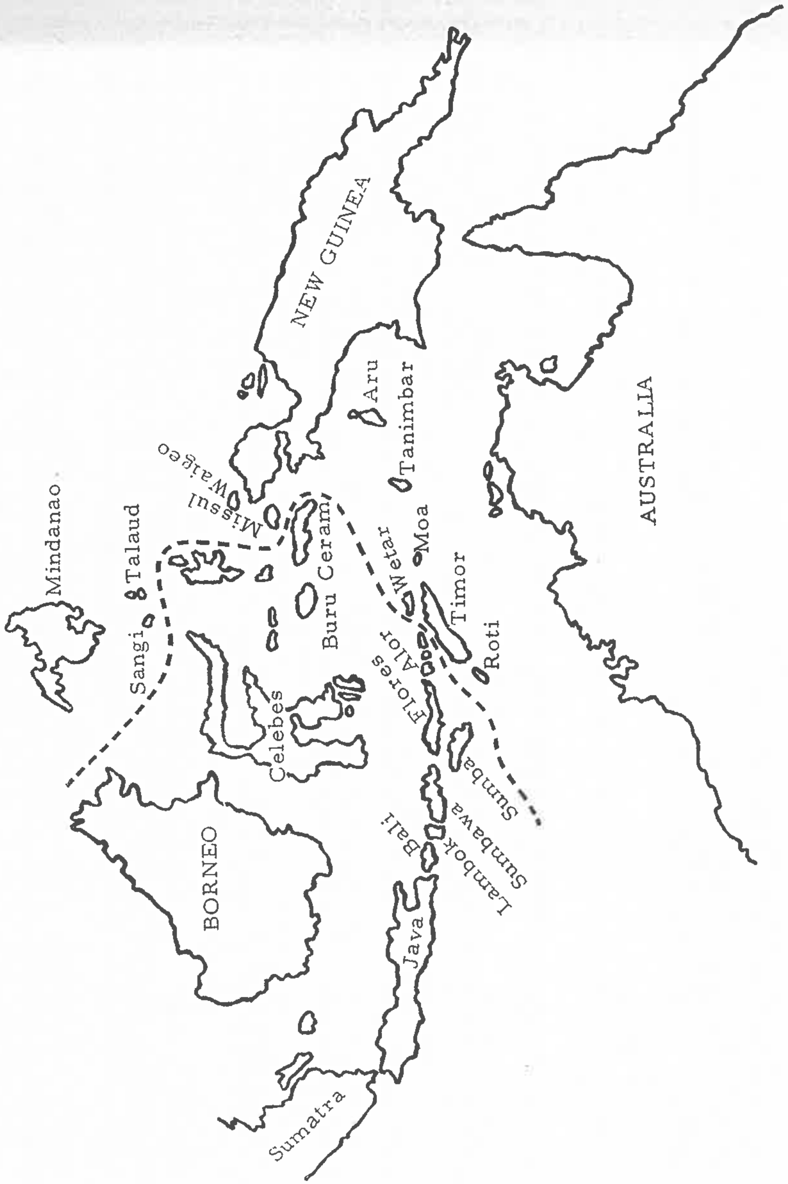
(2) Absence of endemic Brugia malayi infection in the South Pacific

A point of considerable interest is that *Brugia malayi* infection is not endemic in any part of the South Pacific, even though its range of distribution abuts on the western border of this region. On a few occasions *B. malayi* infection has been noted among recent immigrants from south-east Asian countries where this infection is endemic, but it has not been observed among the natives of the South Pacific, even in communities living close to these infected persons. De Rook and Van Dijk (1959) discussing Western New Guinea say: "The presence of *W. malayi* has been confined to imported carriers; no sign of transmission originating from these imports was ever found in spite of a certain abundance of Mansonioides species in several localities."

The range of geographical distribution of *Brugia malayi* covers a very large part of the Oriental Region - India, Ceylon, Malaya, Thailand, Indochina, China, Japan, Korea and Indonesia. Its easterly distribution terminates in the area designated by Dickinson *et al.* (1928) as "Wallacea", comprising Celebes, the Moluccas and the Lesser Sunda Islands, which zoogeographically constitutes the transition zone separating full-scale Oriental fauna on the west from full-scale Papuan fauna on the east (Map 3).

In Celebes, *B. malayi* occurs in the almost total absence of *W. bancrofti* (Brug 1931; Brug & de Rook 1933). In Ceram Island (Moluccas) endemic filarial infection consists of *B. malayi* barring sporadic cases of *W. bancrofti* infection. The easterly distribution of *B. malayi* terminates abruptly in Ceram. In the Lesser Sunda Islands, on the other hand, the transition from *B. malayi* to *W. bancrofti* is gradual. In this chain of islands extending eastwards from Java, the prevalence of *B malayi* progressively diminishes in an easterly direction, side by side with an increase in the prevalence of *W. bancrofti*, so that in the eastermost islands of this group, only *W. bancrofti* is present while *B. malayi* is totally absent. This feature is brought out by the result of investigations carried out by Brug and de Rook (1933). In Sumba Island both *B. malayi* and *W. bancrofti* are present, the former being the dominant infection (malayi 13.7 per cent, bancrofti 2.5 per cent). In Flores to the east of Sumba, *W. bancrofti* is more prevalent than *B. malayi* (malayi 3 per cent, bancrofti 23 per cent). In Timor Island, a solitary case of *B. malayi* infection has been reported. In the islands of Wetar, Roma and Moa, to the north and east of Timor, *B. malayi* is absent and only *W. bancrofti* is present.

The range of distribution of endemic *B. malayi* infection does not extend farther east than the Moluccas and the Lesser Sunda Islands; it does not occur in the Papuan area. Many of the islands lying off the west coast of New Guinea, as for example Missul, Waigeo, Pam, Gam, Salawati and Amsterdam, as also numerous areas on the mainland of New Guinea have been investigated in detail. In none of these areas have any autochthonous cases of



MAP 3. Showing easterly limit of the range of distribution of endemic Brugia malayi

B. malayi infection been observed to occur. The island of Ceram, where B. malayi is endemic, is separated from Fak-Fak on the mainland of New Guinea by a 100-mile stretch of sea. An even smaller gap of ocean, about 60 miles in width, separates Ceram Island from Missul Island. And yet B. malayi infection has not spread out to Missul or to the mainland of New Guinea. The reason for this is not the lack of suitable vectors of B. malayi. Several mosquitoes known to be efficient vectors of B. malayi are present in New Guinea, as for example Mansonia uniformis, M. annulifera and M. indiana. In many parts of New Guinea, M. uniformis occurs in very large numbers.

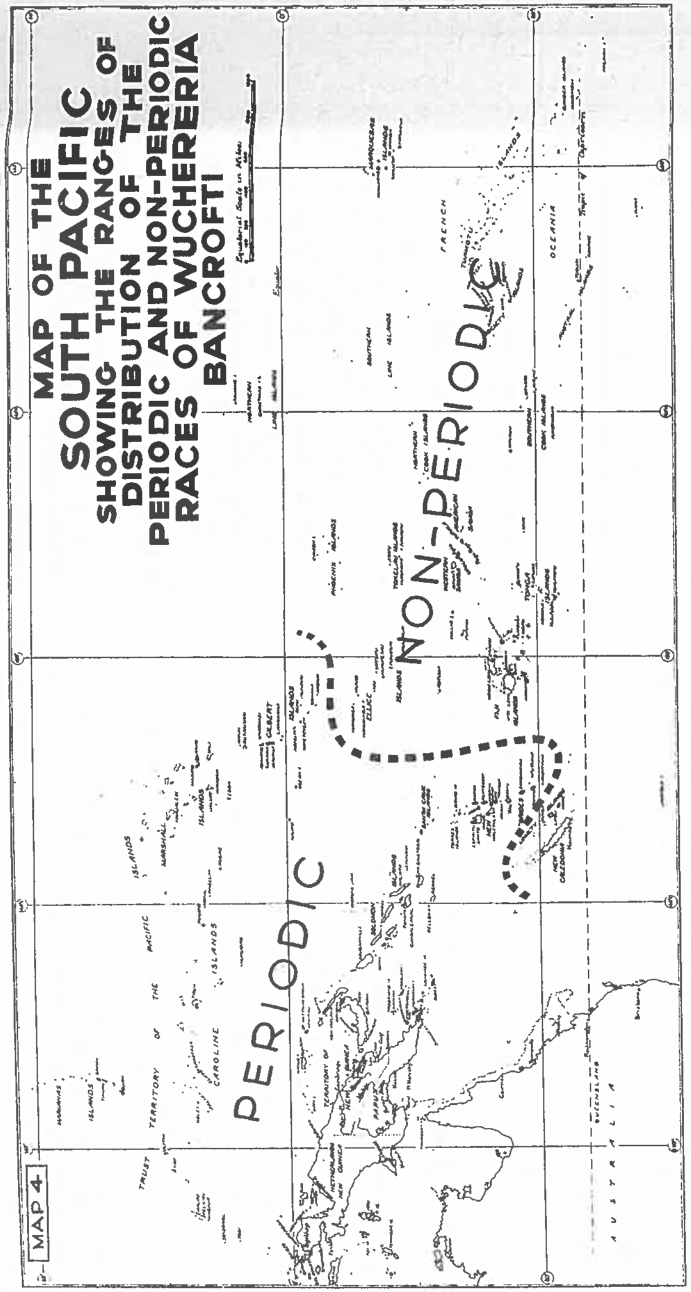
(3) Ranges of distribution of the two races of W. bancrofti

The geographical distributions in the South Pacific of the two races of W. bancrofti, the periodic and the non-periodic, are well-defined. The line of demarcation between their respective ranges of distribution takes an S-shaped course (Map 4). This line runs east to west between Gilbert Islands on the north and Ellice Islands on the south, then takes a southerly course between New Hebrides on the west and Fiji on the east, and after rounding the southern boundary of New Hebrides it runs in a northwesterly direction between New Hebrides on one side and Loyalty Islands on the other. Periodic W. bancrofti occurs in the areas to the north and west of this line of demarcation, while non-periodic W. bancrofti is confined to the islands to the east and south of the line.

Periodic W. bancrofti is endemic in New Guinea, Bismarck Archipelago, Solomon Islands, New Hebrides, Mariana Islands, Caroline Islands, Marshall Islands, Gilbert Islands, Nauru and Ocean Island. Non-periodic W. bancrofti occurs in New Caledonia, Loyalty Islands, Fiji, Tonga, Rotuma, Ellice Islands, Wallis Islands, Niue, Samoa, Tokelau, Cook Islands, Society Islands, Tuamotu Archipelago, Austral Islands and Marquesas Islands. Non-periodic W. bancrofti is not known to occur outside of the South Pacific.

There is no overlapping of the ranges of distribution of the two races of W. bancrofti. Although in two places the ocean gap separating their respective ranges of distribution is as little as 150 to 200 miles, as for example (a) between Gilbert Islands and Ellice Islands, and (b) between New Hebrides and Loyalty Islands, no area is known where the two races are endemically co-existent.

Early reports of the finding of non-periodic W. bancrofti in New Guinea and Bismarck Archipelago have since been found to be incorrect. Based on the finding of microfilariae in blood samples taken during daytime, Fülleborn (1911) reported that in New Guinea and Bismarck Archipelago the microfilaria appeared not to possess a purely nocturnal periodicity; subsequently, however, the same author (Fülleborn 1912) corrected his previous statement and reported that the infections found in these areas were, without exception, of the nocturnal periodic type of W. bancrofti. Breinl's (1915) statement that two types of microfilariae occur in New Guinea, one which does not possess typical nocturnal periodicity and the other which comes into the peripheral blood only during night-time, was evidently based on Fülleborn's



(1911) report. The statement of Brug (1931) to say that "in New Guinea a few cases of aperiodical bancrofti-infection were observed" has not been confirmed by any of the later observers. The observations of several workers, principally Leimena (1928), de Rook (1930 & 1957a), Kariadi (1937) and Hopla (1946), have shown that endemic filarial infection in New Guinea consists solely of the periodic race of W. bancrofti.

(4) Microfilarial periodicity in the two races of W. bancrofti

(a) Periodic W. bancrofti exhibits a well-marked microfilarial periodicity, the microfilaria appearing in peripheral blood during night-time, reaching a peak density around midnight and practically disappearing from peripheral circulation during daytime. Except in persons with heavy microfilarial infestation, it is unusual to find microfilariae in peripheral blood at midday; even in such cases microfilarial density at midday is very low in comparison with the density at mid-night. Several workers have demonstrated the periodicity of periodic W. bancrofti by examination of measured quantities of peripheral blood taken over 24-hour periods (Kariadi 1937 and de Rook 1957a in Western New Guinea; Schlosser 1945 in Solomon Islands; Manson-Bahr and Muggleton 1952 in Ocean Islanders). The pattern of microfilarial periodicity of periodic W. bancrofti in the South Pacific does not differ from that observed in other parts of the world.

(b) Non-periodic W. bancrofti does not exhibit microfilarial periodicity. In the microfilaria carrier the microfilariae occur in the peripheral blood in more or less equal numbers at all hours of the day and night. In Tonga, Thorpe (1896) observed that the microfilariae were found swarming in the blood practically in as great numbers during daytime as at night. In Fiji, Bahr (1912) observed that the microfilaria "occurs in equal abundance in the blood at all hours of the day or night". Fülleborn (1912) studying carriers from Samoa observed that the microfilaria was present in equal numbers in the blood during daytime as during night-time. Determinations of microfilarial densities in measured quantities of peripheral blood over 24-hour periods have been carried out with non-periodic W. bancrofti in several parts of the South Pacific (Bahr 1912 and Manson-Bahr and Muggleton 1952 in Fiji; Eyles et al. 1947 in Society Islands and Tonga; Edgar et al. 1952, and Rosen 1955 in Society Islands; O'Connor 1923 in Samoa, Ellice Islands and Tokelau Islands; Rageau & Estienne 1959 in Wallis Island; Iyengar 1954 and Iyengar & Menon 1956 in New Caledonia; Iyengar 1958 in Niue; McCarthy 1956 in Western Samoa).

Several workers have noted the occurrence of a fluctuation in microfilarial density in peripheral blood in persons infected with non-periodic W. bancrofti. O'Connor (1923) from studies in Samoa, Ellice Islands and Tokelau stated: "The microfilariae here do not show any rhythmic fluctuation in peripheral blood. This was determined by a large series of blood examinations extending over twenty-four hours, at four-hourly intervals. Neither in the indigenes nor in the Chinese and Europeans here examined was any 'periodicity' observed. The utmost that could be suspected was a slight and inconstant tendency for the number of microfilariae in the peripheral blood to recede between the hours of 2 a.m. and 7 a.m." Byrd and St. Amant (1945), from a study of microfilaria carriers in Wallis Islands, noted that although the microfilaria showed no periodicity and occurred in equal numbers during daytime and at night, microfilarial density in peripheral blood was observed to reach a maximum between 4 p.m. and 8 p.m; they expressed the view that this, however, did not constitute true periodicity.

On the other hand, some workers claim that the microfilaria of non-periodic W. bancrofti exhibits diurnal periodicity. Eyles et al. (1947) from a study of a case from Society Islands and another from Tonga stated that peak microfilarial densities occurred between the hours 1200 and 2000, and low densities between 2400 and 0800 hours; on the basis of these findings these authors expressed the view that the term "diurnal periodicity" would more appropriately describe the Pacific filaria than the term "non-periodic". This view was supported by Edgar et al. (1952); of 26 subjects studied by these workers in Tahiti, 24 exhibited greater mean numbers of microfilariae in the late afternoon or evening than in the morning. It was stated that the difference between the morning and afternoon levels of microfilarial density was statistically significant, that maximum numbers of microfilariae appeared in the afternoon with a possible peak around 1900 hour, but that there was no evidence of a definite period when minimum numbers of microfilariae were present.

Rosen (1955) from a study of ten microfilaria carriers in Tahiti noted a tendency in the majority of these cases for microfilarial density to reach a peak incidence in the late afternoon or early evening. Rosen stated: "Although a rhythmic fluctuation in the blood density of microfilariae over a 24-hour period was observed in most of the 10 subjects studied, the magnitude of this fluctuation was very small in comparison with that of other human filariae for which periodicity has been described. Consequently, it is the author's opinion that the term 'diurnal periodicity' suggested as descriptive of Polynesian strains of W. bancrofti (Eyles et al. 1947; Edgar et al. 1952) is inappropriate".

McCarthy (1956) also observed an afternoon increase in the number of circulating microfilariae in a group of Samoans infected with non-periodic W. bancrofti. Of the 23 cases studied, peak microfilarial density in peripheral blood was observed to occur at 1500 hour in 12 cases, at 1800 hour in 8 cases, at 1200 in 2 cases, and at 0500 in one. McCarthy states that the occurrence of peak density between 1500 and 1800 hours in the majority of the cases studied is suggestive of a periodic tendency. But he considers that this afternoon increase in numbers of circulating microfilariae "is not a true periodic quality inherent in the parasite, but is probably due to physiological reactions of the host."

It is common experience that no two samples of peripheral blood taken from the same person and at the same time show even approximately equal microfilarial densities; in fact the variation is often very considerable (Bahr 1912, pp. 5 and 83-84). In view of the very wide variations noted in microfilaria counts even in samples taken at the same time, from

the same individual and by the same observer, it is difficult to say to what extent these fluctuations are due to a tendency of the microfilaria to come into peripheral blood in larger numbers during afternoons and evenings in comparison with mornings and night-time. However, by pooling the figures of large series of observations, variations due to sampling are likely to be minimised. The observations of Edgar et al. (1952), Rosen (1955), McCarthy (1956) and Iyengar (1954) are based on fair numbers of observations, 26, 10, 23 and 6 cases respectively. Taking the averages of each of these series of observations, a small afternoon or evening rise in microfilarial density is noticeable. However, the difference between the afternoon microfilarial density and the density during the morning or night is not marked and never of the magnitude observed between the night and day counts in filariae recognised to have microfilarial periodicity. There seems to be little justification to regard the non-periodic W. bancrofti as "diurnal periodic" on the basis of the small afternoon rise noted in microfilarial density in peripheral blood. In this context, the findings of Manson-Bahr and Muggleton (1952) are of interest. From studies carried out over a period of four days on microfilarial density in capillary blood and in venous blood of two Fijians infected with non-periodic W. bancrofti, these observers stated: "Fluctuations in the number of microfilariae in the capillary blood are liable to occur throughout the 24-hours, but the microfilaria count in the venous blood remains constant" (Manson-Bahr and Muggleton 1952, pp. 308-309).

(5) Status of non-periodic W. bancrofti as a distinct species

Thorpe (1896) stated: "A filaria has been found in the blood of the natives of several islands (in the South Seas) which however in its general appearance does resemble F. nocturna, though it exhibits no 'filarial periodicity', and the measurements taken differ somewhat from those laid down as the dimensions of this species of haematozoa. But these facts do not per se justify the establishment of a new species; so, for the present, we must consider the filaria of the South Sea Islands as identical with the F. nocturna of India and China". In a later communication, Thorpe (1898) stated that although the microfilaria of non-periodic W. bancrofti was identical with that of periodic W. bancrofti, it was possible that the former may constitute a distinct species, especially if the peculiar character of the elephantiasis of the South Pacific, namely, the frequent implication of arms and breasts, was taken into consideration. Manson-Bahr (1941) expressed the view that non-periodic W. bancrofti should be treated as a separate species. He proposed the name, Wuchereria pacifica, for the non-periodic filaria of the South Pacific as a species distinct from W. bancrofti, which name he would restrict to the periodic race. He stated that although the adults and the microfilariae of the non-periodic filaria are morphologically indistinguishable from W. bancrofti, the facts that it has a peculiar geographical distribution, that its microfilaria shows no periodicity, that its intermediate host is Aedes polynesiensis and not Culex fatigans, and that its pathological effects on man are different, would justify treating the non-periodic filaria as a distinct species. In two further communications, Manson-Bahr (1952 & 1953) mentions the finding by Buckley (1952) of certain morphological differences between the adult filaria worms from Fiji and those from other parts of the world as further support to his contention that the non-periodic filaria should be treated *as a species distinct from W. bancrofti.*

Non-periodic W. bancrofti is distinct from the periodic form in certain biological characteristics; the latter exhibits microfilarial periodicity and finds its optimum intermediate hosts in certain night-biting mosquitoes; non-periodic W. bancrofti on the other hand, does not exhibit microfilarial periodicity and its optimum intermediate hosts are certain species of day-biting mosquitoes. There is however little support to the view that the two are morphologically distinct or that they differ in regard to their pathogenicity (vide infra).

(a) Morphology of the two races of W. bancrofti

(i) Microfilaria

The microfilaria of non-periodic W. bancrofti is morphologically indistinguishable from that of periodic W. bancrofti as has been shown by various authorities, principally Leber & Prowazek (1911), Bahr (1912) and Fülleborn (1911, 1912, 1913 & 1929). O'Connor (1923, p. 16) stated: "Although not exhibiting any periodicity, the microfilaria of these islands (Samoa, Tokelau and Ellice Islands) is not different in appearance or structure from the Microfilaria bancrofti of Queensland, and of other parts of the world where periodicity is observed". On the other hand, McCarthy in a recent publication (New Zealand Medical Research in the South West Pacific) stated that the non-periodic microfilaria from Samoa does not conform entirely to the classical descriptions of the microfilaria of W. bancrofti, and that it has some of the characteristics of Brugia malayi and some of W. bancrofti. Of the several points of difference mentioned in that publication as distinguishing the Samoan microfilaria from the microfilaria of W. bancrofti, the important one seems to be the reported occurrence of nuclei extending to the tip of the tail in the Samoan microfilaria. The findings of other workers fail to substantiate this report. Fülleborn (1913 & 1929) from observations on microfilariae from the same area, namely Samoa, showed that the terminal part of the tail is entirely devoid of nuclei; his illustrations of the tail end of microfilariae from Samoa (Fülleborn 1913, plate 1, fig. 18; and Fülleborn 1929, plate 1, fig. 14) clearly bring out this feature. In specimens from Samoa, the last tail nucleus occurred at 94.3 to 96.1 per cent (average 95.3 per cent) of the length of the microfilaria, the terminal part (4.7 per cent of total length) being devoid of nuclei (Fülleborn 1913, p. 64).

In view of McCarthy's report, the writer carried out a detailed re-examination of slide preparations of microfilariae from Samoa (Upolu and Savaii Islands) in the collection of the South Pacific Commission; none of the large number of microfilariae examined showed any nuclei in the terminal part of the tail. The consensus of opinion of authorities is that the microfilariae of the two races of W. bancrofti, the periodic and the non-periodic, are indistinguishable on morphological characters.

(ii) Adult worm

Leiper (1912) made a very detailed morphological study of 5 male and 11 female specimens of non-periodic W. bancrofti from Fiji. The following is quoted from Leiper (1912, 38): "In the course of the present investigation a comparison has been made between the specimens received from Fiji and (A) Cobbold's original type, a female collected by Bancroft in Australia; (B) male and female specimens, in the London School of Tropical Medicine, derived from India; and (C) male and female specimens collected in British Guiana by Dr. Minett. The conclusion arrived at is, that these particular specimens at all events certainly belong to one and the same species, viz. Filaria bancrofti Cobbold, 1877". The identity of species was established from a study of a large number of morphological characters.

Buckley (1952) studied adult filaria worms (non-periodic) from Fiji and compared them with adults of periodic W. bancrofti from British Guiana, Belgian Congo, Philippine Islands and Queensland. In the study of the morphology of the Fijian specimens and, for comparison, specimens from British Guiana, Buckley gave particular attention to the number and distribution of the caudal papillae of the male, the size and structure of the spicules, and the circumoral papillae in both sexes. In none of these criteria could any differences be observed between the two lots of specimens. It was noted that the number and arrangement of the circumoral papillae, 10 in two rows of six and four respectively, were identical in the Fijian and British Guiana specimens. The average length of the non-periodic female was 58.6 mm. (range 50 to 67 mm.) and of the male 27.7 mm. (range 25 to 30 mm.). The average length of the periodic female was 77.5 mm. (range 70 to 90 mm.) and of the male 32.9 mm. (range 28 to 40 mm.). The difference in length between the females of each group and between the males of each group was found to be statistically significant. Buckley says: "It must be borne in mind, however, that there is no certainty that the six non-periodic females, although sexually mature, were fully grown". Another difference noted was that the tail of the immature female of the Fijian specimens was lacking the bulbous swelling which seemed to characterize the females from British Guiana. There was a suggestion that in *en face* view the anterior end of the Fijian specimens was oval in outline and that of the British Guiana specimens was more or less circular. Buckley however stated: "The morphological evidence presented does not of course claim to establish that the non-periodic variety of W. bancrofti is a separate species; but if the differences indicated should prove to be constant in an adequate range of specimens it would tend to support this opinion".

Galliard and Chabaud (1953) reported that the adults of non-periodic W. bancrofti from Tahiti (Society Islands) were morphologically indistinguishable from adults of periodic W. bancrofti from Tonkin (Indochina). The length of the female worm from Tahiti was 76.5 mm., and that of the male was 31.5 mm. The *en face* view of the anterior end was sub-circular and not oval. The tail end of the female had the characteristic bulbous swelling. These observers stated that although the features mentioned by Buckley (1952) for non-periodic W. bancrofti may be constant for specimens that are not fully developed, full-grown specimens of non-periodic W. bancrofti are morphologically indistinguishable from those of periodic W. bancrofti.

The present author (Iyengar 1958, unpublished observations) studied four adult females of non-periodic W. bancrofti from Wallis Island in the collection of the South Pacific Commission. The length of these specimens ranged from 66 to 74 mm. All the four specimens had the bulbous swelling at the tail end, thus confirming the observations of Galliard and Chabaud (1953) on worms from Tahiti.

(iii) Larval instars

The author studied the different developmental stages of non-periodic W. bancrofti in the mosquito host with a view to determine whether they showed any morphological differences from the respective stages of periodic W. bancrofti. These studies were carried out in Samoa and Cook Islands using Aedes polynesiensis as the host, and in New Caledonia with Aedes vigilax as the host. It was noted that both in dimensions and in anatomical details the different larval instars of the Polynesian strain of non-periodic W. bancrofti in Aedes polynesiensis and of the New Caledonian strain in Aedes vigilax were indistinguishable from the respective stages of periodic W. bancrofti of Calcutta and Trivandrum (India) in Culex fatigans. The length of the full-grown infective stage larva of the Polynesian strain of non-periodic W. bancrofti in Aedes polynesiensis ranged between 1370 and 1810 μ, averaging 1560 μ; the length of the infective stage larva of the New Caledonian strain in Aedes vigilax ranged between 1390 and 1820 μ, averaging 1608 μ. These measurements fall well within the range noted for full-grown larvae of periodic W. bancrofti in Culex fatigans in India and elsewhere.

The observations cited above indicate that in none of the stages in the life-history of the parasite, the microfilaria, the adult male, the adult female, and the different larval instars in the optimum mosquito host, is non-periodic W. bancrofti distinguishable from periodic W. bancrofti on morphological characters.

(b) Relative pathogenecity of the two races

Some authorities have expressed the view that the two races of W. bancrofti differ in their pathogenecity, and that non-periodic W. bancrofti is much more pathogenic than periodic W. bancrofti. It has been stated that, in the eastern section of the South Pacific namely the areas falling within the range of distribution of non-periodic W. bancrofti, the incidence of filarial disease is high, the manifestations are often of the severe type, and multiple lesions are common; and that, in the western part of the region namely the area within the range of distribution of periodic W. bancrofti, the incidence of filarial disease is low, the manifestations are of the milder type, and multiple lesions are rare.

Although in many of the areas with non-periodic W. bancrofti infection the incidence of filarial disease is high, there are several areas

with the same type of infection where cases of filarial disease are extremely rare, as for example Tokelau Islands, the atoll islands of Northern Cooks, the Tuamotu Islands, the Austral Islands, New Caledonia and the Loyalty Islands. In the latter areas, cases of elephantiasis are either totally absent or extremely rare, even in communities with high microfilaria rates. Again, in regard to areas where periodic W. bancrofti is the causative organism, although many of them have a low incidence of filarial disease, there are several areas, even within the South Pacific, where the incidence of filarial disease is very high. For instance, high elephantiasis rates, ranging from 4 to 8 per cent of the total population, have been recorded in several endemic foci in New Guinea, e.g., Upper Digul area (Van Dijk 1955, Van Slooten 1955), Inanwatan (de Rook 1959, Van Dijk 1961), Telaga Kokoda villages (de Rook 1957a) and Pam Island (de Rook 1957b). In these areas, severe manifestations of filarial disease and multiple lesions are by no means uncommon.

There is, therefore, little evidence to support the view that the two races differ in their pathogenecity. The prevalence of filarial disease and the severity of its manifestations are not related to the race of W. bancrofti involved. The incidence of filarial disease in an area with endemic filarial infection, whether it is the periodic or the non-periodic race of W. bancrofti, depends on the extent to which the local conditions are favourable for intensive transmission necessary for repeated re-infection and establishment of hyperfilariation in the human host. The factors essential for intensive transmission are the occurrence of high vector density, close and continuous contact of the vector with the human host, and proximity of vector breeding sites to human habitations. Wherever conditions are favourable the intensive transmission, a high incidence of filarial disease prevails. Where facilities for intensive transmission are lacking, the incidence of filarial disease is low. The frequency of occurrence of grosser manifestations of filarial disease usually bears a direct relation to the incidence of filarial disease. Manson-Bahr and Muggleton (1952, p. 320) say: "In the Western Pacific (west of 170° E.) where the microfilaria is nocturnal and the optimum hosts are Culex fatigans and Anopheles punctulatus farauti, the prevalent type of filariasis is milder so that the grosser manifestations of this disease are rare. Possibly this may be due to general ecological causes and to the fact that, owing to the habits of the definitive and intermediary hosts, hyperfilariation cannot readily take place. In the Eastern Pacific, on the other hand, ecological conditions are different, wherever non-periodic filariasis abounds. These coral-girded islands and atolls provide optimum conditions for producing hyperfilariation. It is constant and repeated infections day by day, year by year, which these conditions evoke that produce the more severe clinical manifestations of filariasis, which culminate in elephantiasis. The pathological effects of filariasis would seem to be proportionate to the total number of adult filariae in the body rather than to the variety of that parasite to which they belong".

To recapitulate, the periodic and the non-periodic races of W. bancrofti are biologically distinct. The former exhibits microfilarial periodicity and is adapted for transmission by certain species of night-biting mosquitoes. The non-periodic race does not exhibit microfilarial periodicity and is adapted for transmission by certain day-biting mosquitoes. *In regard to morphological characters, whether in the full-grown adult* stages, the microfilaria, or the different larval instars in the mosquito host, no constant clear-cut differences have been observed between the two races. In regard to their pathogenecity in man, there is little evidence to show that they differ.

It is not proposed to discuss here the propriety of according specific status to the non-periodic race of W. bancrofti on the ground of its biological distinctiveness from the periodic race of W. bancrofti. Pending the acceptance by systematists of the name, Wuchereria pacifica, proposed by Manson-Bahr (1941), the term "non-periodic race of W. bancrofti" is here employed for this race which can be distinguished from the "periodic race of W. bancrofti" by the absence of microfilarial periodicity and its adaptation to transmission by day-biting mosquitoes.

(6) Evolution of the non-periodic race of W. bancrofti

Thorpe (1896), the discoverer of non-periodic W. bancrofti from Tonga, thought that the absence of microfilarial periodicity had been brought about by the irregular habits of the Tongans. The Tongans commonly "employ themselves in conversation, not only at any time during the day, but also at night. Here we have all the conditions necessary for the complete breaking up of filarial periodicity. If sleep is indulged in for short times and at short intervals, and this habit is kept up for several days, filarial periodicity becomes completely broken up, and is no longer maintained - that, in fact, filarial embryos, under such circumstances, are constantly present in the circulation". Thorpe however had an open mind on this question and suggested an experiment "to see if filarial periodicity could be established in a native of Tonga, by causing him to sleep regularly during the night, and not at all in the day-time. The result of such an experiment would go far either to confirm or refute the theory that the filaria of the Tonga Islands is identical with F. nocturna" (Thorpe 1896, p. 924).

Fülleborn (1911 & 1912) studied microfilarial density in day and night peripheral blood in a group of Samoans infected with non-periodic W. bancrofti, then living in Hamburg (Germany). Even though these Samoans led an orderly life for several months continuously, sleeping during night time and keeping awake during day-time, the microfilaria did not exhibit nocturnal periodicity, and occurred in more or less equal numbers in the peripheral blood during day-time as during night-time. Fülleborn showed that the absence of periodicity of the Samoan microfilaria was a character inherent in the parasite and not related to the sleeping habits of the human host.

Bahr (1912) from studies in Fiji observed that the absence of microfilarial periodicity of the Fijian filaria was not related to the peculiarities of the human host, and that in any person who got infested in Fiji, whether he is a Fijian or a non-Fijian, the microfilaria showed

the same lack of periodicity. Bahr suggested that the absence of microfilarial periodicity of the Fijian filaria may be "a partial adaptation to, and impressed on it by, the habits of its usual intermediary host in Fiji, Stegomyia pseudoscutellaris, a mosquito which feeds by day only".

Buxton (1928) propounded the view that the non-periodic race of W. bancrofti had evolved from the periodic race as a result of selection through transmission by a day-biting mosquito vector. The Asian ancestors of the Polynesians, carrying the nocturnal periodic filarial infection with them, left the geographical area of the vectors of typical W. bancrofti and migrated eastwards into Polynesia where the day-biting mosquito, Aedes polynesiensis, became the vector. Although the microfilaria that originally inhabited the ancestors of the Polynesians was nocturnal in its appearance in the peripheral blood and Aedes polynesiensis never bites at night, and the two had different periodicities, there was no insuperable barrier to transmission. The nocturnal periodic microfilaria is present, though infrequent, in the blood even during full daylight, and the vector is active in morning and evening when microfilariae are more frequent. It is possible that Aedes polynesiensis became occasionally infected even before the periodicity of the microfilaria was broken down. As the vector was not nocturnal there was nothing to maintain the nocturnal periodicity of the microfilaria. On the contrary, there was definite selection of these filariae whose larvae were less periodic than most. The irregular sleeping habits of the Polynesians may have contributed to the disappearance of the periodicity through disturbing the orderly daily routine of the microfilaria.

Manson-Bahr (1941), referring to Buxton's view that non-periodic W. bancrofti had evolved from the periodic form as a result of selection through transmission by a day-biting intermediate host, asks why, if the adaptation to the new mosquito host was so perfect, the periodicity of the microfilaria had not become entirely diurnal. Lane, who proposed the hypothesis of synchronized cyclical parturition as the explanation of the nocturnal periodicity of periodic W. bancrofti, expressed the view that the absence of periodicity in non-periodic W. bancrofti might be due to lack of synchronization of microfilarial births (Lane 1948). He contends that the periodic form had probably evolved from the non-periodic form of W. bancrofti which he considers to be the primitive state; that man in the Pacific area, at one time massively migratory, wandered from the areas where Aedes polynesiensis was the vector to areas where Culex fatigans replaced it in commonness; that C. fatigans is only one-twelfth as hospitable to the larva of W. bancrofti as is Aedes polynesiensis; and that the establishment of a nocturnal blood-tide of microfilariae through simultaneous worm parturitions to synchronize with the hour when it was the new insect host's (C. fatigans) habit to feed was an adaptation for increasing the chances of survival of the parasite in a mosquito host which is considerably less hospitable to the parasite. Manson-Bahr (1952 & 1955) also expressed the view that non-periodic W. bancrofti could possibly be the ancestral form from which periodic W. bancrofti had evolved.

Many of Lane's (1948) contentions are unacceptable. In regard to his view that man migrated from Polynesia into areas on the west where Culex fatigans is the common mosquito, all available evidence, historical, anthropological and biological, indicate that man migrated eastwards from South-east Asia and Malaysia into Polynesia and not in the reverse direction. The weight of evidence is in favour of accepting Buxton's (1928) explanation of the evolution of the non-periodic race of W. bancrofti from the periodic race.

It would appear that the non-periodic race of W. bancrofti had evolved from the Micronesian strain of periodic W. bancrofti and not from the Papuan strain. It was mentioned earlier that the major part of the eastward migrations of the ancestors of the Polynesians followed the Micronesian route, through the Carolines, Marshalls and Gilberts, on to Ellice Islands and farther east. The straits between the Gilbert Islands and the Ellice Islands separate two areas which are distinct both climatologically and faunistically, an arid area on the north comprising the major part of the Gilbert Islands with scanty and seasonal rainfall and subject to periodic prolonged droughts, and a wet area on the south (Ellice Islands) with heavy rainfall well distributed all through the year and not subject to droughts. In Gilbert Islands Culex fatigans is common and Aedes polynesiensis is totally absent; in Ellice Islands Aedes polynesiensis is extremely common and C. fatigans is rare. It seems probable that the passage of the ancestors of the Polynesians carrying periodic W. bancrofti infection with them across the straits from Gilbert Islands with fair density of Culex fatigans, into Ellice Islands and the islands farther east with the high density of prevalence of Aedes polynesiensis and little or no C. fatigans facilitated the evolution of the non-periodic race of W. bancrofti as a result of natural selection through transmission by the day-biting intermediate host, Aedes polynesiensis, in the manner originally suggested by Buxton (1928).

(7) Strains of Wuchereria bancrofti in the South Pacific

(a) Periodic W. bancrofti

Two biological strains of the periodic race of W. bancrofti can be differentiated in the South Pacific area, each with a distinct range of geographical distribution and with different preferences in regard to the intermediate host. They are: (i) the Micronesian strain, and (ii) the Papuan strain.

The Micronesian strain, which is akin to, and perhaps identical with the periodic W. bancrofti of Southeast Asia, is transmitted by Culex fatigans. It has a range of distribution covering the Micronesian islands, Marianas, Carolines, Marshalls, Gilberts, Nauru and Ocean. Culex fatigans is its optimum intermediate host. The Micronesian strain does not undergo normal development in the mosquito vectors of the Papuan strain: Anopheles farauti and A. punctulatus are inhospitable to the Micronesian strain (Byrd & St. Amant 1959). Although isolated in the tiny islands of Micronesia scattered over a vast expense of the Pacific Ocean and well removed

from the Asian mainland, the close association of the Micronesian strain with Culex fatigans, the customary intermediate host of Asian W. bancrofti, has served to preserve its original biological characteristic in regard to host preference.

The Papuan strain of periodic W. bancrofti is distinct from the Micronesian strain in that it does not find its optimum intermediate host in Culex fatigans and is adapted for transmission by a number of other species, chiefly Anopheles farauti, A. koliensis and A. punctulatus. This strain occurs in New Guinea, Bismarck Archipelago, Solomon Islands and New Hebrides.

Although under conditions of experimental infection, the Papuan strain is capable of undergoing complete development in Culex fatigans, many observers have noted that this mosquito is not a favourable host (Brug & de Rook 1933; Heydon 1935; Hopla 1946; Backhouse & Heydon 1950; and McMillan 1960). In Upper Digul (New Guinea), Brug and de Rook (1933) noted complete development of the parasite only in 2 out of 13 experimentally infected C. fatigans; these authors state that in this area W. bancrofti has for a very long time been transmitted by other mosquito vectors and, in consequence, has lost its capacity to develop in C. fatigans. Heydon (1935) quoting Backhouse's experimental studies in Rabaul (New Britain) stated that C. fatigans was only very slightly hospitable to Papuan W. bancrofti. In New Guinea, Hopla (1946) recorded a low experimental infection rate (12.3 per cent) in C. fatigans. In New Britain Backhouse and Heydon (1950) found that 17.4 per cent of 115 C. fatigans mosquitoes experimentally fed on a microfilaria carrier took the infection. Although McMillan (1960) obtained a slightly higher experimental infection rate (25.5 per cent), the rate of development of the parasite was observed to be very slow: full grown larvae were not seen earlier than $17\frac{1}{2}$ days. McMillan considers that C. fatigans is not an efficient vectof of W. bancrofti in New Guinea.

This lack of adaptation for development in Culex fatigans appears to be a character inherent in the Papuan strain. Culex fatigans occurring in New Guinea is not biologically different from C. fatigans occurring in other parts of the world; Willemse (1960) showed that periodic W. bancrofti of South America developed normally in C. fatigans from New Guinea.

(b) Non-periodic W. bancrofti

We have in the South Pacific two closely related strains of non-periodic W. bancrofti, the Polynesian and the New Caledonian strains, with distinct ranges of geographical distribution and transmitted by different vectors. The Polynesian strain occurs in Fiji, Rotuma, Ellice Islands and the island groups extending eastwards from these to Tuamotu and Marquesas; it is transmitted by certain species of the Aedes (Stegomyia) scutellaris group, namely A. polynesiensis, A. pseudoscutellaris, A. tongae, A. rotumae and A. cooki. The New Caledonian strain occurs in New Caledonia and Loyalty Islands; it is transmitted by Aedes (Ochlerotatus) vigilax. This strain appears to have been derived from the Polynesian strain through Wallis Islanders and Samoans (and probably also Tongans) who migrated in small numbers to Loyalty Islands and New Caledonia several centuries ago. Coming from areas where the vectors are Aedes (Stegomyia) polynesiensis and allied species to an area where these species are totally absent, the parasite found an efficient intermediate host in another, though entirely different, day-biting mosquito, namely Aedes (Ochlerotatus) vigilax. In spite of its isolation from the parental Polynesian strain and its adaptation to a different mosquito host, the New Caledonian strain does not differ markedly in its biological characteristics from the Polynesian strain. Under experimental conditions, the New Caledonian strain undergoes normal development in Aedes polynesiensis and A. pseudoscutellaris, the vectors of the Polynesian strain (Backhouse & Woodhill 1956). The Polynesian strain differs from the New Caledonian strain in that it does not undergo normal development in Aedes vigilax (Burnett 1960).

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IV. MOSQUITO FAUNA OF THE SOUTH PACIFIC

Iyengar (1960) had discussed the characteristics, affinities and distribution of the mosquito fauna of the South Pacific. Its antiquity is seen from the occurrence of the palaeogenic genus, Bironella, with a distribution restricted to New Guinea and neighbouring islands. An interesting feature of the mosquito fauna of the South Pacific is the evolution of several endemic complexes of closely allied species.

Forty genera or subgenera, and 313 species are known to occur in the South Pacific*. The richness of the mosquito fauna varies markedly in different parts of the region. The continental island of New Guinea with its very large area, and varied topographical and

*Since the work of Iyengar (1960), many new species of mosquitoes from the South Pacific area have been described by Belkin (1962).

climatic conditions, has a very rich mosquito fauna. As one proceeds away from New Guinea, the fauna gets markedly poorer, so that in the islands of the eastern part very few genera and species are present. Excluding the two ubiquitous species, Culex fatigans and Aedes aegypti, there are 39 genera or subgenera, and 218 species in New Guinea; in Solomon Islands, 27 and 62 respectively; in New Hebrides, 13 and 20; in Fiji, 10 and 16; in Samoa, 5 and 9; and in Marquesas, 2 and 2.

Anopheline mosquitoes are restricted in their distribution to New Guinea, Bismarck Archipelago, Solomon Islands and New Hebrides. In New Guinea we have as many as 20 species of Anopheles, whereas in Solomon Islands there are 8 species, and in New Hebrides only one.

On the basis of the constitution and affinities of the mosquito fauna, Iyengar (1960) has divided the area into four faunistic zones, Papuan, Micronesian, Polynesian and New Caledonian.

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V. VECTORS OF WUCHERERIA BANCROFTI

In the South Pacific we have a multiplicity of vectors of W. bancrofti. As many as 15 species of mosquitoes belonging to 7 different subgenera are important vectors in the South Pacific. The vectors of periodic W. bancrofti are Anopheles (Anopheles) bancroftii, Anopheles (Cellia) farauti, A. (C.) koliensis, A. (C.) punctulatus, Mansonia (Mansonioides) uniformis, Aedes (Finlaya) kochi, Culex (Culex) annulirostris, C. (C.) bitaeniorhynchus, and C. (C.) pipiens fatigans. The vectors of non periodic W. bancrofti are Aedes (Stegomyia) polynesiensis, A. (S.) pseudoscutellaris, A. (S.) tongae, A. (S.) rotumae, A. (S.) cooki, and Aedes (Ochlerotatus) vigilax.

The ranges of distribution of these mosquitoes in the South Pacific and the areas where they are of importance in the transmission of filarial infection are furnished in Table 2.

All the nine vectors of periodic W. bancrofti are night-biting mosquitoes. Anopheles farauti, A. koliensis and A. punctulatus breed in marshes, ditches and ground pools exposed to sunshine; while A. farauti breeds in brackish as well as in fresh water, A. koliensis and A. punctulatus breed only in fresh water. Anopheles bancroftii

TABLE 2

Vectors of Wuchereria bancrofti in the South Pacific

Species	Range of distribution in the South Pacific	Areas where the species is of importance as a vector
(a) Vectors of periodic W. bancrofti:		
Anopheles farauti	New Guinea, Bismarck Arch., Solomon Is., New Hebrides	New Guinea, Bismarck Arch., Solomon Is., New Hebrides
Anopheles koliensis	New Guinea, Solomon Is.	New Guinea, Solomon Is.
Anopheles punctulatus	New Guinea, Bismarck Arch., Solomon Is.	New Guinea, Bismarck Arch., Solomon Is.
Anopheles bancroftii	New Guinea, Admiralty Is.	New Guinea
Mansonia uniformis	New Guinea, Bismarck Arch., Solomon Is.	New Guinea
Aedes kochi	New Guinea, Bismarck Arch.	New Guinea
Culex annulirostris	Practically throughout South Pacific	New Guinea
Culex bitaeniorhynchus	New Guinea, Caroline Is., New Caledonia	New Guinea
Culex pipiens fatigans	Practically throughout South Pacific	Caroline Is., Mariana Is., Marshall Is., Gilbert Is., Nauru, Ocean I.
(b) Vectors of non-periodic W. bancrofti:		
Aedes polynesiensis	Fiji, Ellice Is., Wallis Is., Samoa, Tokelau Is., Cook Is., Society Is., Austral Is., Tuamotu Arch., Marquesas Is., Pitcairn I.	Fiji, Ellice Is., Wallis Is., Samoa, Tokelau Is., Cook Is., Society Is., Austral Is., Tuamotu Arch., Marquesas Is.
Aedes pseudoscutellaris	Fiji	Fiji
Aedes tongae	Tonga	Tonga
Aedes cooki	Niue	Niue
Aedes rotumae	Rotuma	Rotuma
Aedes vigilax	New Guinea, Solomon Is. New Hebrides, New Caledonia, Loyalty Is., Fiji.	New Caledonia, Loyalty Is

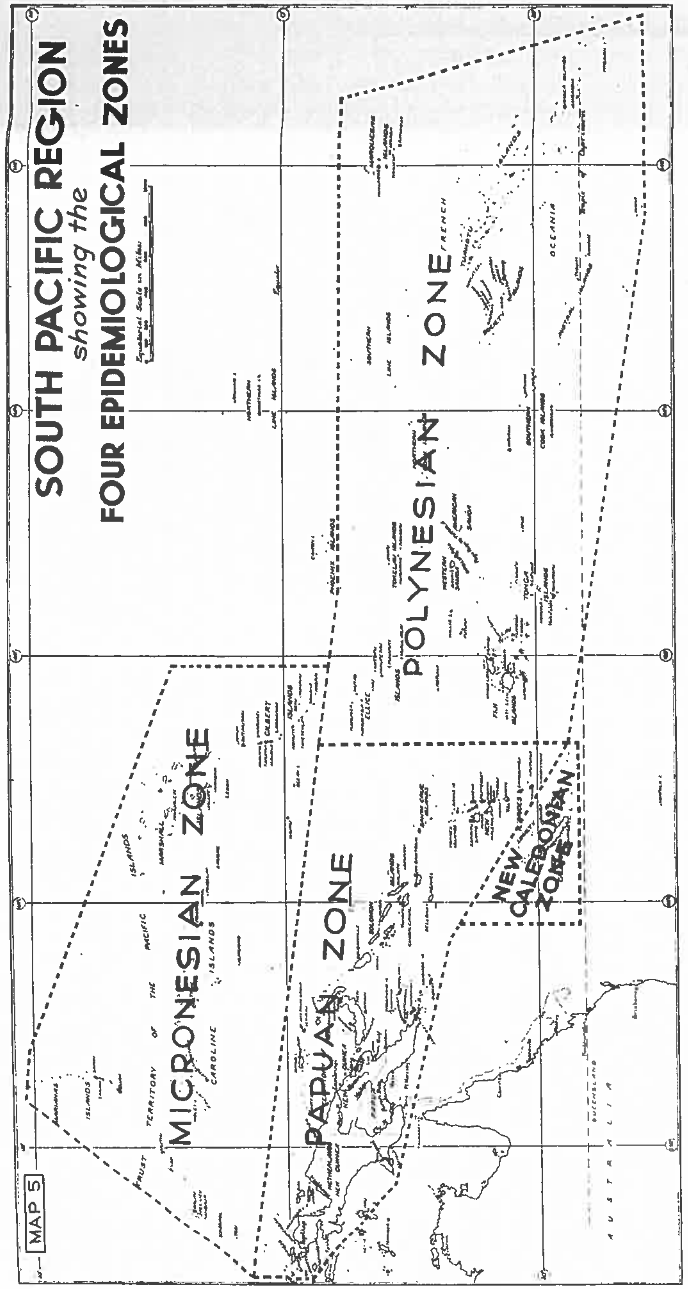
breeds in fresh water swamps shaded by forests or emergent aquatic vegetation. Mansonia uniformis breeds in marshes; the larva of this mosquito is adapted for obtaining its supply of oxygen from air-cavities within the stems and roots of certain aquatic plants. In the absence of aquatic vegetation of the type suitable for sustaining the life of its larval stages, M. uniformis cannot breed. In addition to the presence of such aquatic vegetation, the occurrence of a small amount of suspended organic matter in the water is essential for facilitating intensive breeding of this mosquito. Culex annulirostris and C. bitaeniorhynchus breed in marshes; a small amount of organic contamination of the water renders the breeding site more favourable for these species to breed. Aedes kochi breeds exclusively in water held in the leaf-bases of Pandanus trees. Culex fatigans breeds chiefly in ditches, drains and pools in the vicinity of habitations; contamination of the water with decaying organic matter favours intensive breeding of this mosquito.

The six vectors of non-periodic W. bancrofti are day-biting mosquitoes; they are not active during night-time. Aedes polynesiensis, A. pseudoscutellaris, A. tongae, A. rotumae and A. cooki, all of which belong to the Aedes scutellaris group, breed in small containers, chiefly rain-water cisterns and barrels, coconut-shells, tin-cans, and tree-holes. These species have a limited range of flight and are rarely to be found at distances of more than 100 yards from their breeding sites. Aedes vigilax breeds in saline and brackish marshes that are well exposed to sunshine. This mosquito has a large range of flight and is often found in numbers even at distances of several miles from breeding sites.

VI. THE FOUR EPIDEMIOLOGICAL ZONES

The South Pacific region is heterogeneous from the point of view of the epidemiology of filariasis. We have here two biological races of W. bancrofti, the periodic and the non-periodic, each with a well-defined range of geographical distribution. Within the range of distribution of periodic W. bancrofti, two distinct areas are recognizable: (1) the Micronesian islands with a strain of periodic W. bancrofti akin to the Asiatic strain, transmitted by Culex fatigans; and (2) the Papuan area with a different strain of periodic W. bancrofti adopted for transmission primarily by species of the Anopheles punctulatus group. Within the range of distribution of non-periodic W. bancrofti there are two distinct areas: (1) Fiji, Ellice Islands and all Polynesian islands to the east of these, where the vectors are certain species of the Aedes scutellaris group; and (2) New Caledonia and Loyalty Islands where Aedes vigilax is the vector.

As the different vectors differ widely in their bionomics and breeding habitats, the factors controlling filarial endemicity vary considerably from one area to another. Following Iyengar (1959), the South Pacific region may be divided into the following four epidemiological



zones on the basis of the type of filarial infection involved and the vectors responsible for the transmission (Map 5):

1. The Micronesian Zone (Marianas, Carolines, Marshalls, Gilberts, Nauru and Ocean Island) with periodic W. bancrofti transmitted by Culex fatigans.

2. The Papuan Zone (New Guinea, Bismarck Archipelago, Solomon Islands and New Hebrides) with periodic W. bancrofti transmitted by one or more of the species, Anopheles farauti, A. koliensis, A. punctulatus, A. bancroftii, Mansonia uniformis, Aedes kochi, Culex annulirostris and C. bitaeniorhynchus.

3. The Polynesian Zone with non-periodic W. bancrofti transmitted by one or more of the species, Aedes polynesiensis, A. pseudo-scutellaris, A. tongae, A. rotumae and A. cooki; this zone includes Fiji, Rotuma, Ellice Islands and all the island groups extending eastwards from these to Tuamotu Archipelago and Marquesas Islands.

4. The New Caledonian Zone (New Caledonia and Loyalty Islands) with non-periodic W. bancrofti transmitted by Aedes vigilax.

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VII. MICRONESIAN ZONE

(1) Caroline Islands

The Caroline Islands lie between latitudes 3° and 10° N., and extend from the Palau group (longitude 130° E.) on the west to Kusaie (longitude 163° E.) on the east. The group comprises about 960 islands with a total land area of about 600 square miles. The vast majority of the islands are very small in size. The Palau group, Yap group, Truk Islands, Ponape and Kusaie, are high islands of volcanic origin; all others are coral atolls. The Carolines are divided into four administrative districts, Palau District on the west, Yap and Truk in the middle, and Ponape on the east.

The climate of the Carolines is tropical-oceanic. Temperature is uniformly warm, and atmospheric humidity is high. Rainfall is heavy, about 120 inches annually over the major part of the Carolines. A few of the islands in the eastern section (Ponape and Kusaie) receive about 180 inches of rainfall annually. Rainfall occurs all through the year and there is no distinct dry season.

The total population of the Carolines is estimated at 48,000. The villages in the Carolines, as elsewhere in Micronesia, are fairly compact, with habitations close to one another. The people are Micronesians, excepting two small islands in the south-eastern part of the group, namely Kapingamarangi and Nukuoro, inhabited by people of Polynesian stock.

Periodic W. bancrofti has a wide distribution in the Carolines. The microfilaria rates for the different islands based on Pipkin's (1953) investigations are furnished in Table 3. None of the various island groups is entirely free from endemic filarial infection. A few individual islands, as for example Tobi, Sonsorol, Pingalap, Kusaie and Nukuoro appear to be free; in a few others, e.g., Yap Island, Angaur and Ulithi, microfilaria rates are very low (1 to 3 per cent). In the majority of the other islands, microfilaria rates are higher than 16 per cent. In Keyengel, Koror, Moen, Fefan, Uman, Puluwat, Murillo and Mokil, the microfilaria rates range between 23 and 27 per cent. Three islands, Babeldob, Satawal and Truk. have very high microfilaria rates (32 to 37 per cent). Broadly speaking the incidence of filarial infection is higher in the western part of the Carolines than in the eastern part. Pipkin (1953) observed that the microfilaria rates varied from 48 per cent in isolated areas on Babeldob Island in the western Carolines, through 27 to 36 per cent in the Truk-Mortlock area of central Carolines, to 8 to 24 per cent in the Ponape-Mokil area in the eastern Carolines, fading out to isolated cases in the southern Marshalls.

Detailed information on the incidence and distribution of filarial disease in the Carolines is lacking. Cases of elephantiasis have been reported from a number of islands in the Carolines. German workers of the period 1900 to 1917 reported the finding of cases of elephantiasis from Yap, Elato and Lamotrek (Yap District), Truk (Truk District), and Ponape and Nukuoro (Ponape District). More recently, McNair et al (1949) reported the finding of 14 cases of "clinical filariasis" from four islands of Yap District (Wolei, Ulithi, Ifalik, and Elato). Although cases of filarial disease have been noted to occur in many parts of the Carolines, the incidence of filarial disease is very low (Farner 1944). Pipkin (1953) observed that cases of filarial disease were rare even in communities with a high incidence of filarial infection.

The primary vector of W. bancrofti in the Caroline Islands is Culex fatigans. A natural infection rate of 4.9 per cent was recorded in C. fatigans from Palau (Pipkin 1953). Although C. annulirostris was also found naturally infected, in the vast majority of the infected specimens the infection consisted only of first stage larvae of W. bancrofti; one third stage larva was seen in a single specimen out of 211 examined (Pipkin 1953). Culex annulirostris is not a vector of importance

TABLE 3

Microfilaria rates of the different islands of the Carolines (from Pipkin 1953)

Island	Number examined	Microfilaria rate
Palau District:		
Tobi	81	0.0
Sonsorol	59	0.0
Angaur	102	1.0
Pelilieu	108	16.6
Keyengel	74	23.0
Babeldob	510	37.3
Koror	158	24.1
Yap District:		
Yap	205	1.0
Ulithi	203	3.4
Wolei	95	17.8
Wotegai	60	18.3
Faralep	55	18.2
Satawal	104	31.7
Ifalik	115	17.4
Lamotrek	106	17.9
Truk District:		
Moen	143	24.5
Tol	123	19.4
Fefan	71	22.5
Uman	200	24.5
Pulusuk	100	21.0
Puluwat	68	26.5
Ulul	75	20.0
Nomwin-Fenanu	67	11.9
Murillo	100	27.0
Ponape District:		
Ponape	37	8.1
Mokil	75	24.0
Nukuoro	171	0.0
Pingalap	199	0.0
Kusaie	165	0.0

in the Carolines. Culex fatigans occurs in all the inhabited areas. It breeds in ground pools in the vicinity of human habitations as well as in domestic containers for storing rain-water. This mosquito has a preference for stagnant ground pools polluted with organic matter, and does not ordinarily breed in water collections free from organic contamination or in those far removed from habitations. Large numbers of larvae of C. fatigans are commonly found in pools in the yards of native huts (Bohart & Ingram 1946), in sump holes and in soakage pits for coconut husk. To a smaller extent, it breeds in drums for storing water and in tin-cans, especially when they contain food particles or decaying vegetable matter.

In the Caroline Islands the incidence of filarial infection varies considerably in the different areas. The general incidence of the infection is high. In 19 of the 29 islands for which reliable data are available, the microfilaria rates are higher than 16 per cent, and in a few as high as 32 to 37 per cent (Table 3). Villages situated on undulating or hilly terrain with sensible natural drainage, are either free from endemic filarial infection, or have low microfilaria rates. In such areas facilities for C. fatigans breeding are comparatively poor. Villages with large populations have higher microfilaria rates than those with small populations. The extent of breeding of C. fatigans and the prevalence of the adult mosquito depend on the extent of stagnant water collections subject to organic contamination and this in turn is directly related to the density of human population. Another controlling factor is rainfall. In the Carolines, the microfilaria rates seem to vary inversely as the amount of rainfall. In the eastern Carolines which receive very heavy rainfall, microfilaria rates are much lower than in the western Carolines where rainfall is comparatively less. Heavy rainfall renders a breeding site unfavourable for heavy breeding of Culex fatigans through dilution and lowering of the concentration of organic matter in the water.

The incidence of filarial disease in the Caroline Islands is very low. Pipkin (1953) stated that although cases of clinical filariasis, some with elephantoid involvement, were observed in the Carolines, the paucity of such pathological manifestations in the presence of relatively high incidence of filarial infection in the population suggested a poorly adapted mosquito vector. He observed that the incidence of natural infection in Culex fatigans was low even in areas with high microfilaria rates. In the opinion of Pipkin, the vector seems to be able to maintain endemic microfilaraemia in the population of the Carolines, but it is "seldom able to produce sufficiently heavy infection to commonly produce obvious clinical involvement".

The paucity of cases of filarial disease in the Caroline Islands seems to be due to lack of facilities for intensive transmission of filarial infection. Two factors of importance for intensive transmission are (1) proximity of vector breeding sites to habitations, and (2) high vector density. The first of these two factors is present in these villages; the breeding sites of the vector, C. fatigans, occur close to

habitations. As regards the second factor, the density of C. fatigans in these rural areas never reaches the level commonly reached in urban areas with high population densities, large sullage output, and plentiful opportunities for this mosquito to breed. While vector density in the endemic areas of the Caroline Islands is high enough for effective transmission of W. bancrofti infection and for the maintenance of fair to high microfilaria rates in the populations, it is not high enough to ensure intensive transmission necessary for the establishment of hyperfilariation in a significant proportion of the population, and in consequence the incidence of filarial disease is low.

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(2) Mariana Islands

The Mariana Islands, to the north of central Carolines, comprise a chain of 16 high islands of volcanic origin, extending from Guam on the south to Parallon de Pajaros on the north. They lie between latitudes 12° and 21° N., and between longitudes 144° and 146° E. Guam, the largest island of the group, has an area of 206 square miles and a population of 36,000. All the other islands are comparatively small in size, and many of these are uninhabited; their total area is 247 square miles and their population 8,200. The climate is hot and humid; annual rainfall is about 80 inches.

Endemic filarial infection in Mariana Islands consists of the periodic race of W. bancrofti (Crow 1910, Knott 1944 a & b). The infection is at present largely restricted to Saipan Island (Knott 1944a); cases of filarial disease are however extremely rare. Knott (1944b) observed stray cases of filarial infection among natives of Rota and Tinian islands.

At the present time W. bancrofti infection is not known to be endemic in Guam (Reeves & Rudnick 1951). During the early years of the present century Crow (1910) located an endemic focus of W. bancrofti infection in Ynarajan on the south-east coast of Guam. Of 244 persons examined by Crow from different parts of Guam Island, 13 were found to carry microfilariae of W. bancrofti; the infection was noted to be closely limited to the region of Ynarajan; no cases of clinical filariasis were seen. Kindelberger (1912) stated that up to that time microfilariae had been found in the blood of only 11 persons in Guam, and that there were no endemic cases of filariasis. Later observations show that the Ynarajan focus of filarial infection has since disappeared (Pipkin 1953). Knott (1944b) examined 517 natives of Agana district (on the west coast of Guam) and failed to find filarial infection in any of them. He however observed a solitary case of elephantiasis in a native of Guam, a man aged 65 years. This finding does not contradict the views of Pipkin that endemic filarial infection had disappeared from Guam during the past fifty years. Knott stated that this case of elephantiasis developed the condition at the age of 26 years, that is to say about the year 1905 when at least one active endemic focus of filarial infection existed in Guam as evidenced by Crow's (1910) report.

Of the other islands of the Marianas, W. bancrofti infection is definitely known to be endemic only in Saipan. Knott (1944a) found 13.5 per cent of 243 natives examined by him in Saipan positive for microfilariae in their blood. Cases of elephantiasis were rare; a solitary case of elephantiasis was recorded by Knott among the total population of Saipan (approximately 7,000). Elephantiasis was probably of more common occurrence in Saipan some 50 years ago; Schnee (1911) in his report for the year 1909-1910 mentioned the finding of cases of elephantiasis in Saipan.

Culex fatigans is the vector of W. bancrofti in Saipan (Knott 1944a). It is a common mosquito in the inhabited areas of the Marianas, and breeds in domestic water containers as well as in ground pools in the vicinity of habitation (Bohart & Ingram 1946; Reeves & Rudnick 1951).

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(3) Marshall Islands

Marshall Islands, situated to the east of the Carolines and to the north of the Gilberts, lie between latitudes 5° and 15° N., and between longitudes 162° and 173° E. The islands of this group are disposed in two parallel chains running north-west to south-east and about 130 miles apart, the Rotak chain on the east and the Ralik chain on the west. All the islands are coral atolls; the land is flat and low-lying, barely a few feet about sea level. Of the 34 atolls comprising the Marshalls, only 22 are inhabited. The total land area is about 66 square miles and the total population 14,000. Average population density is 211 per square mile. Some of the islands are fairly densely populated; for instance, Namorik with a land area of one square mile has a population of 500.

Climate is uniformly warm and humid. Rainfall is on the average about 80 inches in the year. Jaluit, at the southern end of the Ralik chain, receives heavy rainfall, over 150 inches annually. The northern islands of the Marshalls receive little rain, often less than 50 inches.

The type of filarial infection endemic in the Marshall Islands is periodic W. bancrofti (Knott 1944). Filarial infection occurs only sporadically in the Marshall Islands; it has been reported from only two islands, namely Majuro and Namorik, and even in these the microfilaria rates are very low, 1.0 and 3.6 per cent respectively (Pipkin 1953). Most of the islands of the group appear to be free from endemic filarial infection, as for example Ebon, Ailingalap, Kwajalein, Namu, Lai and Jaluit (Knott 1944; Pipkin 1953).

Cases of filarial disease are extremely rare in the Marshall Islands. Some fifty years ago, a few cases of clinical filariasis were reported among the populations of Jaluit, Arno, Majuro and Mili atolls (Born 1911), but none were found on Ebon atoll (Born 1915). None of the more recent observers found any appreciable incidence of filarial disease in the Marshall islands. Cases of filarial disease were absent in all the three atolls investigated by Pipkin (1953), namely Majuro, Namorik and Ebon. Knott (1944) found a solitary case of elephantiasis in Kwajalein Atoll. No cases of elephantiasis are known to occur in Arno Atoll (Usinger & La Rivers 1953; Milhurn 1959).

No information is available in regard to the vector of W. bancrofti in Marshall Islands. It is probable that Culex fatigans, the confirmed vector in other parts of the Micronesian Zone, is the local vector in the Marshalls. This mosquito has a wide distribution in the inhabited areas; it breeds in domestic rain-water containers, and in shallow wells close to habitations. The rain-water barrels are for the most part without covers and collect trash; the shallow wells are subject to surface contamination. Although Culex fatigans occurs in all the inhabited areas, its density of prevalence is very low, which would account for the low incidence of filarial infection in the population, and the practical absence of cases of filarial disease.

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(4) Gilbert Islands

The Gilbert Islands constitute the central link in a long chain of islands stretching from Marshall Islands on the north to Ellice Islands on the south. The group straddles the equator and extends over 400 miles from Little Makin in the north-west (latitude 3°30' N.) to Arorae in the south-east (latitude 3° S.). The 16 coral islands and atolls comprising the Gilberts are separated from one another by large stretches of ocean. The total land area of the group is 114 square miles. The islands are very low, rarely more than 10 feet above sea level. The total population of Gilbert Islands is 33,000; average density of population is high, about 290 per square mile.

Climate of the Gilberts is equatorial-oceanic, characterized by uniformly high temperature and high atmospheric humidity. Mean temperature in Apamama is 82° F., and the mean relative humidity varies between 77 and 81 per cent. The amount of rainfall varies not only from island to island but also from year to year. In the two islands in the northern part of the group, namely Little Makin and Butaritari, rainfall is heavy and varies little from about 120 inches a year. Towards the south, rainfall diminishes steadily to reach a minimum in the southerly islands. The islands situated between latitudes 1° and 3° S. lie close to, or within, the dry

equatorial belt and receive about 40 inches of rainfall annually. These islands are subject to periodical droughts, of which the cycle appears to be 5 to 7 years. During drought years rainfall may be extremely scanty, sometimes as little as 3 inches in the year (Sachet 1957). The only source of fresh water is collected rain-water and water from shallow wells, many of which are brackish and subject to surface contamination.

The type of filarial infection endemic in the Gilbert Islands is the periodic race of Wuchereria bancrofti (Lambert 1928; Knott 1944; Stempien 1944; Byrd & St. Amant 1959). Schlosser (1945) from a study of microfilaria carriers from the Gilbert Islands showed that the microfilaria exhibited a pronounced nocturnal periodicity. He however stated that the periodicity was less clearly defined than what was noted by him in microfilaria carriers from the Solomon Islands. The total number of microfilariae in blood smears taken at 1930 hours from 27 microfilaria carriers from Gilbert Islands was 1,280, while the number of microfilariae in blood smears taken from the same persons during daytime was 114. Byrd & St. Amant (1959) also showed that microfilariae were more commonly found in the peripheral blood taken during daytime in carriers from the Gilbert Islands than in carriers from the Solomon Islands. They reported that the microfilaria count in day blood in Gilbert Islanders was 9.3 per cent of the night count, whereas in Solomon Islanders it was only 2.3 per cent of the total night count. These observations were not based on midnight counts, but on blood smears taken between 1930 and 2030 hours. Backhouse and Heydon (1950) found that the total microfilaria count in blood smears taken at night from 3 carriers from the Gilberts was 70, and during daytime, 2. There is no evidence to show that the periodicity of the microfilaria of the Gilbert Islands differs markedly from that of either the Asiatic strain or the Papuan strain of periodic W. bancrofti.

The Gilbert Islands represent the south-easterly limit of the range of distribution of the Micronesian strain of periodic W. bancrofti. An ocean gap of about 200 miles separates Arorae Island, the southernmost island of the Gilberts, from Nanumea, the northernmost island of the Ellice group. Although the Gilberts are so close to the Ellice Islands where non-periodic W. bancrofti infection is widely prevalent, this type of infection has not spread into the Gilbert Islands. No cases of non-periodic W. bancrofti infection have been reported to occur in any of the natives of the Gilbert Islands who have never left their homes. People from the Ellice Islands come frequently to the Gilberts. There is a lot of traffic between the Ellice Islands and the Gilbert Islands which form part of a single territory called the Gilbert and Ellice Islands Colony, with its administrative headquarters in Tarawa in the Gilberts. And yet, non-periodic W. bancrofti is not endemic in the Gilberts. The mosquito fauna of the Gilberts is different from that of the Ellice Islands. Aedes polynesiensis, the vector of non-periodic W. bancrofti, does not occur in the Gilbert Islands.

Filarial infection is endemic in most of the islands of the Gilberts. The incidence of the infection, however, varies in the different islands of the group. In the islands in the northern part of the group, microfilaria rates are very low; Little Makin 0.0 per cent: Butaritari 0.1 per cent; Abaiang 0.3 per cent (Marshall 1945). These *islands receive heavy rainfall.* In the islands of central Gilberts, microfilaria rates are higher: Tarawa 21 to 25 per cent (Rudyard 1949); Maiana 6.5 per cent (Marshall 1945); Apamama 5 per cent (Knott 1944). In the islands of the southern Gilberts, namely Nonuti, Tapeteuea, Beru and Nukunau, endemic filarial infection has been noted to occur (Stempien 1944) but data on microfilaria rates are not available. Considering that cases of elephantiasis have been reported from these islands, it seems likely that the microfilaria rates of these islands are fairly high. The islands of the southern group are among the most densely populated islands of the Gilberts, with population densities of 227 to 441 per square mile according to Catala (1957).

Gilbert Islands have long been known to have a very low incidence of filarial disease. Hercouet (1897) stated that the Gilbertese are fairly free from elephantiasis. Both Brunwin (1909) and O'Reilly (1915) stated that the Gilbert Islands are free from endemic filarial disease. Lambert (1924) observed that elephantiasis and filarial fever were uncommon. Knott (1944) stated that in the Gilbert Islands there is not much clinical filariasis and that filarial infection occurs in the practical absence of cases of elephantiasis. Cases of filarial fever and of elephantiasis have been reported to occur in the southern group of the Gilberts (Lambert 1928). Buxton (1928) mentions the finding of cases of elephantiasis in Nonuti, Nukunau, Tamana and Arorae in the southern Gilberts. No data are available on the incidence of elephantiasis on any of the islands. Although cases of elephantiasis are rare, hydrocele among adult males is common on many of the islands of the Gilberts (Buxton 1928; Knott 1944).

Stempien (1944) observed that the Culex fatigans experimentally infected with the Gilbertese strain of periodic W. bancrofti, the parasite underwent normal development and reached the infective stage in 11 days. Epidemiological evidence, supported by the finding of experimental hospitability, indicates that C. fatigans is the vector of periodic W. bancrofti in the Gilbert Islands. Culex fatigans is the only mosquito which has a wide distribution in the inhabited areas; it occurs in close association with human habitations.

Culex fatigans is a highly anthropophilic species. Its breeding sites are restricted to the immediate vicinity of habitations (Marshall 1945). It breeds in drains, taro-pits and wells, besides domestic rain-water containers. The most important breeding sites of C. fatigans in the Gilberts are wells and rain-water containers. There are many wells in the villages. These shallow wells being subject to surface contamination are favourable breeding sites for C. fatigans. The rain-water containers are without covers and often collect trash; the decaying vegetable matter derived from such trash favours C. fatigans breeding. The rain-water containers however do not breed C. fatigans as prolifically as the wells.

In the Gilbert Islands, although filarial infection is widespread, filarial disease is uncommon. Hydroceles have been observed to be common, but cases of elephantiasis are rare. Buxton (1928) thought that the rarity of cases of elephantaisis in the Gilbert Islands may be due to the low rainfall. The main reason seems to be that vector density is not high enough for intensive transmission of filarial infection. Although vector breeding sites occur close to habitations and climatic conditions are favourable for transmission of filarial infection (Stempien 1944), vector density is not high. Because of the porous soil, surface water collections are few. The shallow wells and rain-water barrels constitute the perennial breeding sites of C. fatigans. While these produce sufficient numbers of the vector mosquito to maintain low to moderate incidence of microfilariaemia in the populations of these islands, which often manifests itself as hydroceles in adult males, vector density does not reach the level required for producing an appreciable incidence of elephantiasis. The Gilbert Islands exemplify an area of low filarial endemicity. Acton and Rao (1930) have shown that areas of low filarial endemicity are characterized by the frequent occurrence of hydrocele and rarity of crural elephantiasis.

Early observers (Hercouet 1897; Brunwin 1909; O'Reilly 1915) reported that the Gilbert Islands were practically free from elephantiasis. As more information became available, cases of elephantiasis were reported from different islands of the group. This gave the impression that there had occurred a progressive increase in the incidence of elephantiasis. For instance, Lambert (1928) stated: "Until recent times there was no history of filarial fever and no elephantiasis in the Gilbert Islands; in recent years it has apparently been creeping up through the group. This is evidenced by some natives with filarial fever and some with elephantiasis in the lower Gilbert Islands". The proximity of the southern Gilberts to the Ellice Islands where elephantiasis is known to be rife, led to the belief that the disease had spread out from the Ellice Islands into the Gilberts. Stempien (1944) stated: "The disease (filariasis) undoubtedly has been spreading from the Ellice Islands. The migrations of these natives and their transportation to different islands for purposes of labour have been factors in the spread of the disease to non-endemic areas". O'Reilly (1915) says: "The Resident Commissioner of the Protectorate states that there can be no doubt that elephantiasis was brought into the Ellice Islands as a result of the introduction of native pastors and teachers from Samoa. The London Missionary Society is now beginning to send Samoan pastors to the Southern Gilbert group, and it is pointed out that unless the landing of Samoan and Ellice natives in the Gilberts is immediately controlled, there is serious danger that it may soon prove too late to prevent the establishment of elephantiasis in these islands". With a view to prevent the introduction of infected persons into Gilbert Islands, an ordinance was issued by the local Government during 1917 empowering the Health Officer to "prohibit the landing of any passenger, arriving by any vessel that has come from or called at any place or port in Samoa, who fails to produce a recent certificate to the effect that the person had been examined and found to be free from microfilaria".

It is not known if these regulations were enforced. Considering that the infection endemic in Samoa and Ellice Islands is non-periodic W. bancrofti, and that its vector, Aedes polynesiensis, is absent in Gilbert Islands, any importation of microfilaria carriers from Samoa and Ellice Islands will have little effect on the local filarial endemicity in the Gilberts which is due to periodic W. bancrofti transmitted by Culex fatigans.

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(5) Nauru

Nauru is a small raised coral island situated about 26 miles south of the equator and at longitude 167° E. It is about 4 miles long and 2 miles in width, with an area of 8½ square miles. Nauru is in the form of an oval hump rising to about 220 feet above sea level. It represents a type of formation in which the coral substratum has been raised to a considerable height above sea level. The central raised part of the island is overlaid with a thick solid mass of high grade phosphate-rock, the value of which is said to be almost beyond computation. A narrow flat coastal strip skirts the island on all sides.

The climate of Nauru is equatorial-oceanic. It is hot and humid all through the year. Annual rainfall is on the average about 80 inches. As it lies close to the western edge of the dry equatorial belt of the South Pacific, Nauru is subject to considerable variations in rainfall, and often experiences prolonged droughts. During 1950, for instance, rainfall in Nauru was only 12 inches.

The total population of Nauru is about 4,300, of which 2,100 are Nauruans; the rest of the population is made up of imported labour, consisting of Gilbertese, Ellice Islanders and Chinese, recruited for short terms for working the phosphate deposits on the island. The Nauruans constitute the only permanent population of the island, the others being transient. Average density of population is about 500 per square mile. The actual population density of the inhabited areas is very much higher. The central plateau, which comprises seven-eights of the total area of the island, is uninhabited. Almost the entire population is crowded into the narrow coastal strip, about one furlong in width, situated between the sandy beach and the coral cliffs at the edge of the central plateau; these settlements are highly congested.

The only sources of fresh water are collected rain-water and water from wells. There are numerous wells on Nauru; in many of these the water is brackish. As the wells are subject to surface contamination, they breed Culex fatigans in large numbers. There are also many water-holes of varying dimensions, most of which are prolific breeding sites for C. fatigans.

Periodic W. bancrofti infection is endemic in Nauru (Bray 1931; Grant 1933; Heydon & Bearup 1940). An investigation conducted during 1926 showed that 28.8 per cent of the entire Nauruan population (excluding infants) harboured microfilariae in their blood (Bray 1931). During 1932, of 354 Nauruans examined by Grant (1933), 36.1 per cent were positive for microfilariae in night peripheral blood.

Unlike most other parts of the Micronesian zone Nauru has an appreciable incidence of filarial disease. In 1926, Bray (1931) found that 1.3 per cent of 1,151 Nauruans (all ages) had elephantiasis, chiefly of the legs and scrotum; a few cases of elephantiasis mammae were also seen. In the majority of the cases, the affections were of the mild type; in a solitary case, a boy aged 16 years, the affection was gross. Although the elephantiasis rate in Nauru is only 1.3 per cent, other manifestations of filarial disease are very common. Bray stated: "*High fevers, lymphangitis, adenitis and abscess formation* were extremely frequent. Ten per cent of the male population had small chronic hydrocele". Grant (1933) recorded an elephantiasis rate of 1.4 per cent in Nauru. The cases of elephantiasis were mostly affections of the scrotum or leg; one case of elephantiasis of the arm was noted. Grant observed that muscle abscesses, filarial fever, adenitis and hydrocele were common. Smyth's (1955) report shows that filarial fever, muscle abscesses and hydrocele are of frequent occurrence in Nauru: the cases of elephantiasis seen by Smyth were mostly of the leg; he recorded a few cases of elephantiasis of the scrotum and one case of elephantiasis of the penis.

The vector of W. bancrofti in Nauru is Culex fatigans. Grant (1933) found natural infection with full-grown larvae of W. bancrofti in C. fatigans collected from habitations in Nauru. Heydon & Bearup (1940) working in Nauru observed complete development of the parasite in both C. fatigans and C. sitiens under conditions of experimental infection. They however stated that the former species was a more favourable host for the parasite than C. sitiens. The latter was not found infected in nature. As it is a wild species only infrequently found in dwelling houses, and as it breeds in salt marshes often far from habitations, it is unlikely that C. sitiens could be of any importance as a vector of W. bancrofti in Nauru.

Culex fatigans is the most common mosquito in Nauru. It breeds in ground pools, cess-pits, and wells situated close to habitations. It has a preference for water collections polluted with organic matter. The prevalence of C. fatigans in the congested settlements in the narrow strip of flat land lying between the sandy beach and the coral cliffs at the edge of the central plateau, is high. Ample facilities are offered for heavy breeding of this mosquito. The level of subsoil water is high and there is a profusion of water collections like ground pools, ditches, water-holes, cess-pits and wells. The high density of human population in these areas accounts for the heavy organic contamination of the water collections. All these factors favour prolific breeding of C. fatigans. Conditions here are favourable for intensive transmission of filarial infection; vector density is high, and numerous breeding sites of the vector occur close to habitations.

An anti-mosquito campaign consisting of the treatment of mosquito breeding sites with larvicidal oil has been in operation in Nauru since 1922. During recent years, considerable improvement has been effected in the sanitary condition of the inhabited areas on Nauru. In addition to mosquito control operations, reclamation of swampy areas, and minor drainage measures, a scheme for re-housing the people of Nauru was started in 1948. As a result, congestion in the villages and settlements has been partially relieved. These may possibly account for the drop in the microfilaria rate from 29 per cent in 1926 (Bray 1931) to an

estimated 15 per cent in 1950 (based on the adult microfilaria rate of 19.7 per cent according to Nauru Administration Report for 1951). During 1952, a scheme for mass treatment of microfilaria carriers with diethylcarbamazine was put into operation in Nauru; the microfilaria rate dropped from the pre-treatment level of 15 per cent in 1952, to 7.1 per cent during 1953-54, and to 6.9 per cent during 1954-55 (Smyth 1955).

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(6) Ocean Island

Ocean Island is a small, isolated island (area 2½ square miles), situated at latitude 0°52' S., and longitude 169° E., about midway between Nauru and Gilbert Islands. Like Nauru, Ocean Island is a raised coral island rising to a height of 265 feet above sea level, and covered with enormous, rich deposits of phosphatic rock.

The climate of Ocean Island is hot and humid. Average annual rainfall is about 80 inches. Being close to the dry equatorial belt, Ocean Island is often subject to droughts, and the amount of rainfall may fluctuate widely from year to year (Table 4).

TABLE 4

Annual rainfall in Ocean Island for 1909 to 1919

Year	1909	1910	1911	1912	1913	1914	1915	1916	1917	1917	1919
Rainfall in inches	19	28	141	136	77	154	80	14	16	100	174

There is very little vegetation on Ocean Island. There is no surface water. Rain infiltrates through the porous rock and collects in wells and caverns where Culex fatigans breeds in large numbers.

There is no permanent population on Ocean Island. The present inhabitants consist of imported labour, mostly Gilbertese, recruited for working the phosphate deposits on the island. The original natives of Ocean Island, known as Banabans, belong to the Micronesian race. During the last World War, after the Japanese seized the island in August 1942, the Banabans were deported to different islands in the South Pacific, to Kusaie in the Carolines, to Tarawa in the Gilberts, and to Nauru. After the surrender of the Japanese in October 1945, all the Banabans exiled in the Carolines, the Gilberts and Nauru, numbering about 1,000, were brought together and settled on Rambi, a small island in the Fiji group to the east of Vanua Levu. Since December 1945, the Banabans have been living in a new environment, namely on Rambi Island which is non-endemic for periodic W. bancrofti.

No information is available on the incidence of filarial infection among Banabans prior to 1943 when they were living in their original homes on Ocean Island. Information on the incidence of filarial disease is meagre. Reports of the Banaban Hospital for that period make no mention of cases of elephantiasis. Hydrocele, however, appears to have been fairly common among adult males. In the records of the Banaban Hospital for the years 1935, 1936 and 1939, mention is made of 26, 20 and 5 Banabans operated upon for hydrocele during the respective years.

During 1939, Heydon & Bearup (quoted by Backhouse 1953) examined blood films taken by day from 34 natives of Puakonikai village on Ocean Island, and failed to find microfilariae in any of them. As the blood films were taken during daytime and as the infection is the periodic W. bancrofti, no definite conclusions can be drawn from these negative findings. In December 1948, Isimeli Rakai demonstrated the periodicity of the microfilaria found in the Banabans, and this was confirmed in 1950 by Manson-Bahr & Muggleton (1952). Of 146 Banabans on Rambi examined by Isimeli Rakai during 1948, 5.5 per cent were positive for microfilariae in night peripheral blood.

Several noteworthy points are brought out by the studies of Manson-Bahr & Muggleton (1952) on Banabans living on Rambi Island. In spite of about 6 per cent of the population having demonstrable microfilaraemia, and the presence in the Banaban settlements of Culex fatigans, an efficient intermediate host of periodic W. bancrofti, there has been no spread of the infection, nor any new cases of filarial disease. None of the 20 children who had been brought to Rambi originally as babies showed filarial infection, nor any of the adults that were previously known to be free from the infection. Although the parasite occurring in the Banabans is capable of undergoing complete development to the infective stage in Culex fatigans, none of the mosquitoes collected from houses occupied by these people was found naturally infected with W. bancrofti. Evidently the density of C. fatigans in the Banaban settlements on Rambi is not high enough for effective transmission of filarial infection.

Other points of interest are as follows. Periodic W. bancrofti infection originally acquired by the Banabans while resident on Ocean Island has persisted in the carriers for a period of well over four years in the absence of re-infection. The microfilaria in the infected Banabans has retained its characteristic nocturnal periodicity even though these persons have been living for a prolonged period in an area which is non-endemic for periodic W. bancrofti. There have been no new cases of filarial disease among the Banabans since their arrival in Rambi; even persons with fairly heavy microfilaraemia (microfilaria counts of 60 to 120 per 20 cmm. of blood) have remained asymptomatic.

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VIII. PAPUAN ZONE

(1) New Guinea

The continental island of New Guinea lies between the equator and latitude 12° S., and between longitudes 129° and 154° E. It is approximately 1,300 miles in length and about 500 miles broad at its widest central part; its area is about 320,000 square miles. A line running north to south at the middle of the island along longitude 141° E. divides it into its two political sections, Western New Guinea and Eastern New Guinea.

New Guinea is traversed from east to west by a huge range of mountains, the central cordillera. This main axial highland consists of a jumble of parallel mountain ranges and elevated plateaus, separated by deep, densely afforested valleys. Some of the peaks of the central mountain chain rise to heights of about 15,000 feet and are ice-flanked. Towards the west, this broad arterial highland narrows down abruptly to a width of about 20 miles at the neck of Vogelkop, to broaden out into folds of mountains in the middle part of Vogelkop. Running parallel to the central cordillera and lying to the north of it is a smaller mountain chain consisting of a succession of coastal ranges. In between the central cordillera and the coastal range on the north, lies an extensive intermontane trough; the western part of this trough is the Meervlakte, a large, flat, mountain-locked plain, under 200 feet in elevation and comprising the basins of the Rauffaer and the Idenburg rivers; the eastern part is made up of the basins of the Sepik and Ramu rivers.

The north coast rises steeply from the sea, so that the flat areas of the northern littoral are small, narrow and discontinuous. The southern littoral is continuous and extensive, stretching out from the foot-hills to the sea. The main part of the southern littoral to the south of the central cordillera consists of the delta plains of several large rivers chiefly the Digul, Fly-Strickland and Eiland. *These rivers, arising in the mountains which receive heavy rainfall,* carry large loads of alluvium and build up their deltas over the slowly subsiding continental shelf on the south. In most places the coastal strip is slightly higher than the immediate hinterland. This broad water-logged lowland, about 450 miles in length and 200 miles in width is traversed by meandering rivers which, during the wet season, spread out to link up numerous lakes and swamps into an enormous expanse of shallow water. The northern part of the southern littoral is covered with dense tropical rain-forest vegetation, while the southern part consists of grassy swampland. The large Frederick-Hendrik Island, about 85 miles by 75 miles and separated from the mainland by the narrow 2-mile wide Princess Mariane Straits, is similar in topography to the southern littoral and forms an integral part of it. This island consists of an extensive marsh enclosed all around by a narrow belt of raised wooded land. To the west of the main part of the southern littoral are two small littoral areas which are similar in character, flat and water-logged, namely the eastern part of Fak-Fak peninsula and the southern part of Vogelkop.

Of the large number of islands lying off the mainland of New Guinea, the important ones are: Missul, Batanta, Salawati, Pam, Gam, and Amsterdam, off the coast of Vogelkop; Schouten Islands in Geelvink Bay; the island groups at the eastern end of New Guinea, namely the Louisiade, d'Entrecasteaux, and the Trobriand Islands.

The climate of New Guinea is tropical, except in the highlands where temperate conditions prevail. Rainfall is heavy, generally over 100 inches annually. The eastern part of New Guinea receives a greater amount of rainfall than the western part. In some areas, as for example around Huon Gulf and the hilly areas in the interior, rainfall is very heavy, over 150 inches in the year. Atmospheric humidity is high.

Much of the interior of New Guinea is covered with dense forests and is very sparsely populated. The coastal plains are comparatively more densely populated. The total population of New Guinea is estimated at 2.3 million, but this figure is only approximate. Average density of population is very low, about 7 per square mile.

Endemic filarial infection in New Guinea consists of the periodic race of W. bancrofti. The microfilaria exhibits characteristic nocturnal periodicity (Fülleborn 1912; Leimena 1928; de Rook 1930 & 1957a; Kariadi 1937; Hopla 1946). The average microfilaria counts in 25 cmm. of finger blood taken at different hours of the day from six microfilaria carriers from Manokwari in Western New Guinea as determined by Kariadi (1937) were as follows:

Hour	1000	1300	1600	1900	2200	0100	0400	0700
Microfilaria counts	1.5	0.0	3.7	29.3	78.7	80.3	63.7	9.7

In a second series of observations made by Kariadi on 10 carriers from the same area, the average microfilaria counts in 25 cmm. of finger blood were as shown below:

Hour	1200	1800	2100	2400	0300	0600	0900
Microfilaria counts	1.3	22.3	47.3	52.7	71.5	23.2	0.9

De Rook (1957a) recorded the observations made by W. de Groot on microfilarial periodicity in four carriers from Negeri Besar village in Telaga Kokoda swamp (Western New Guinea). The findings are reproduced below:

Hour	Microfilaria count in 20 cmm. of finger blood (average of 4 cases)
0300	30.3
0600	40.3
0900	3.5
1200	0.0
1500	0.0
1800	1.3
2100	25.3
2400	45.8

Filarial infection has a wide distribution covering most of the flat lowlying coastal areas along the north and east coasts of New Guinea, the inland extensions of these coastal areas along river basins, the coastal areas of the off-shore islands, and the interior of the southern littoral. Areas bordering on marshes and those close to mouths of rivers usually have a high incidence of the infection. Filarial infection is not known to be endemic in hilly and undulating areas, nor at elevations of more than 1,000 feet.

In the central intermontane trough of New Guinea, cases of filarial disease have been reported to occur among the populations of Meervlakte and the Sepik Basin, but little information is available on the incidence of filarial infection or of filarial disease in these sparsely populated and insufficiently explored areas.

In the southern littoral, the distribution of filarial infection is largely restricted to the hinterland lying between the coastal zone and the undulating area at the foot-hills. Several areas in the southern littoral are known to have high microfilaria rates, as for example Inanwatan, Seged, Arundai and Telaga Kokoda area in the southern part of Vogelkop, Arguni Bay area and Kaimana in the eastern part of Fak-Fak peninsula; some of the interior areas of the main southern littoral, e.g., Upper Digul, Lower Koah, and Bamgi-Ia areas. Van Dijk (1958b) has summarized the information on the distribution of W. bancrofti infection in the main part of the southern littoral of New Guinea.

The coastal strip as well as the whole of Frederick-Hendrik Island are free from endemic filarial infection except for sporadic cases. In the hinterland, the incidence of the infection rises progressively reaching a moderate incidence in the upper reaches of the Maro and Bian rivers, the Bamgi-Ia area and the Obaa district; further inland is a belt of high filarial endemicity in the Upper Digul and Lower Koah areas. To the north of this hyperendemic belt, the incidence of filarial infection suddenly drops, so that the undulating and hilly areas at the foot-hills are free from endemic filarial infection.

On the off-shore islands, the distribution of filarial infection is restricted to the flat lowlying areas along the coast, the undulating as well as the hilly areas being free from the infection. On several islands, the microfilaria rates are high, as for example Waigeo, Salawati, Missul and Pam (off Vogelkop), and the southern coastal areas of Japen Island (Schouten Islands).

Filarial disease occurs in most of the areas with high incidence of filarial infection. The manifestations are elephantiasis of the limbs and genital affections in the male. Elephantiasis rates for the different endemic areas vary widely; in the majority of the foci, the elephantiasis rate is only 1 per cent or less. In a relatively small number of foci, high elephantiasis rates (4 to 11 per cent of the total population) have been recorded, as for example Pam Island (west of Vogelkop); Imboean, Sanformon, Wefiani, Saukorem and Wekari (north coast of Vogelkop); Inanwatan and Telaga Kokoda villages (South Vogelkop); Sombroko (Wandammen); and Upper Digul (interior of southern littoral).

The classic vector of periodic *W. bancrofti* in other parts of the world and in the Micronesian zone, namely *Culex fatigans*, is not of importance in the transmission of filarial infection in New Guinea. This mosquito is absent in most of the endemic areas, and in such of those where it does occur, its incidence is too low to be of epidemiological significance. *Culex fatigans*, according to most authorities, is of comparatively recent introduction into New Guinea, and it occurs in appreciable numbers only in urban and quasi-urban areas; its distribution bears no relation to that of endemic filarial infection which is restricted to rural areas. Further, it has been demonstrated by various workers that *C. fatigans* is a poor intermediate host for the Papuan strain of periodic *W. bancrofti*.

Until a few years ago, it was generally believed that anopheline mosquitoes constituted the only vectors of *W. bancrofti* in New Guinea. Recent researches of de Rook (1957a & b, 1959), and Van Dijk (1961) have shown that several culicine mosquitoes are of importance as vectors in many parts of Western New Guinea. On the basis of the finding of (a) natural infection with larval stages of *W. bancrofti*, (b) hospitability for complete development of the parasite under conditions of experimental infection, and (c) numerical prevalence in endemic areas, the following species of mosquitoes are considered to be important vectors in New Guinea: *Anopheles farauti*, *A. koliensis*, *A. punctulatus*, *A. bancroftii*, *Mansonia uniformis*, *Aedes kochi*, *Culex bitaeniorhynchus*, and *C. annulirostris*. The multiplicity of vectors of *W. bancrofti* that we find in New Guinea is unmatched in any other part of the world.

Three species of the *Anopheles punctulatus* group, namely *Anopheles farauti*, *A. koliensis* and *A. punctulatus*, are the important vectors in the northern and eastern coastal areas of New Guinea and on the off-shore islands. High rates of natural infection with *W. bancrofti* have been recorded in all the three species. Under experimental conditions, all of them are very hospitable to the parasite, facilitating its normal development to the infective larva stage. The three species differ somewhat in their distribution. *Anopheles farauti* is the dominant species in the coastal areas; in the hinterland, it is largely replaced by *A. koliensis* and *A. punctulatus*, the former being the more common mosquito. Broadly speaking, *A. farauti* may be considered the important vector in the coastal areas, and *A. koliensis* in the interior areas (Van Dijk 1959).

The breeding sites of *A. farauti* and *A. koliensis* are permanent or semi-permanent water collections such as swamps, ditches and slow-running streams. Whereas *A. farauti* breeds in fresh as well as in brackish water, *A. koliensis* does not tolerate brackish water. *Anopheles punctulatus* breeds mainly in temporary collections of water like rain-pools, roadside ditches and hoof-prints. One factors essential for the breeding of each of the three species is that the water of the breeding site is exposed to open sunshine; water collections even sensibly shaded by vegetation are unsuitable as breeding sites for these species. Much of the facilities offered for the breeding of these mosquitoes is due to man-made causes, chiefly the clearing of bush, jungle and forests for agricultural or other purposes, resulting in exposure to sunshine of water collections which were naturally shaded by vegetation. Such bush clearance may not be of material importance from the point of view of causation of filariasis if the cleared areas are far from habitations; it is only when areas adjacent to villages are extensively cleared of bush that conditions are rendered favourable for the establishment of filarial endemicity.

Anopheles bancroftii has a wide distribution in New Guinea; in many parts of the southern littoral and in Meervlakte it occurs in large numbers. The only area where it has been known to transmit *W. bancrofti* is the Upper Digul area. Here, of 655 specimens of *A. bancroftii* examined by Elsbach (1937), 11 per cent were found naturally infected. Under experimental conditions this mosquito was found to be highly hospitable to the parasite; 49 per cent of the mosquitoes that took the infective feed became infected, and the parasite reached the full-grown infective stage in a remarkably short period of time, 6 to 8 days.

Anopheles bancroftii breeds in large, permanent, sheltered stretches of water which are well-shaded by forest vegetation or by aquatic vegetation of the emergent type. It does not breed in water exposed to sunshine. The densely afforested areas of New Guinea with meandering rivers, swamps, and dead loops of rivers, as we have in the interior of the southern littoral and in the central intermontane trough, form the favourite haunt of this mosquito. It is also common in the grassy swampland in the lower part of the southern littoral (Assem & Van Dijk 1958), where it breeds in permanent stretches of water overgrown with emergent aquatic vegetation.

In the Upper Digul area Elsbach (1937) found both A. bancroftii and A. farauti naturally infected with W. bancrofti. The absence of endemic filarial infection in many of the areas where Anopheles bancroftii is dominant, and species of the A. punctulatus group are absent or low in incidence, may support the view that A. bancroftii is of importance only as a secondary vector, and that by itself it is not capable of maintaining filarial endemicity. As against this view, we have the finding of a high natural infection rate in A. bancroftii, the occurrence of full-grown filaria larvae in an appreciable proportion of the naturally infected specimens, the high hospitability of the species to the parasite when experimentally infected, and the rapid development of the parasite to the infective stage (Elsbach 1937). These findings indicate that A. bancroftii is, by itself, a very efficient vector. The absence of endemic filarial infection in many of the areas with high density of A. bancroftii may possibly be due to the fact that its breeding sites do not ordinarily occur close to habitations except in the densely afforested areas of Upper Digul and Lower Koah rivers. In other areas, the villages are only infrequently located right inside dense forests and close to extensive marshes breeding A. bancroftii.

Aedes (Finlaya) kochi is an efficient vector of W. bancrofti in New Guinea. In Pam Island, off the western tip of Vogelkop, de Rook (1957b) recorded a natural infection rate of 15.6 per cent in A. kochi. The infected specimens showed filaria larvae in all stages of development, and several specimens harboured more than a single brood of the parasite. When fed on a microfilaria carrier, 121 (or 72 per cent) of 168 specimens of A. kochi took the infection; the parasites developed normally and reached the infective stage in 11 to 13 days. The role of this mosquito in the transmission of filarial infection in nature is however determined by the extent of its contact with the human population, and the proximity of its breeding sites to villages. This species, although it was found to attack man in large numbers on Pam Island, is essentially a wild species not ordinarily associated with human habitations. It has a specialized breeding habitat, and breeds exclusively in the water held in the leaf-axils of pandanus trees, which usually grow in and around mangrove swamps and along banks of tidal rivers. In areas where an abundance of pandanus occurs in the proximity of villages and where rainfall is sufficiently high to facilitate intensive breeding of Aedes kochi, this mosquito may be of importance as a vector of W. bancrofti. The only area where Aedes kochi has so far been found naturally infected with W. bancrofti is Pam Island. Here it is associated with high density of prevalence of two other vectors, namely Anopheles farauti and Culex annulirostris. It is not know whether Aedes kochi, by itself, is capable of maintaining a high level of filarial endemicity in the absence of a major vector like Anopheles farauti. Deland (1951) observed that in the coastal areas of New Guinea and the Solomon

Islands, the filariasis-affected villages were invariably those with large numbers of pandanus trees close to habitations; he expressed the view that Aedes kochi was responsible for the hyperendemic filariasis, and that species of the Anopheles punctulatus group were responsible for the general filarial endemicity. In this context, de Rook (1957b) says: "As yet it has not been proved that this mosquito (Aedes kochi) alone is able to cause endemic filariasis without the assistance of a more important vector. The high endemicity of filariasis on the island of Pam with its numerous pandanus trees agrees with Deland's (1951) opinion that major filariasis occurs only in localities where pandanus trees grow near the houses. When evaluating the presence of pandanus trees as the cause of hyperendemic filariasis, it should be taken into account that pandanus trees often grow in or along swamps in which Anopheles farauti and other members of the punctulatus group breed prolifically".

Mansonia (Mansonioides) uniformis is an important vector of W. bancrofti in New Guinea. It breeds in marshes with certain types of aquatic vegetation capable of sustaining the life of its larval stages. In the absence of the suitable type of aquatic vegetation, its larvae do not thrive. Another factor which favours intensive breeding of the mosquito is the presence of organic matter in the water (Assem 1959). In the villages of Telaga Kokoda marsh, M. uniformis is an important vector (de Rook 1957a); it seems likely that it is also of importance in other parts of New Guinea such as the southern littoral (Van Dijk 1958a), and possibly also in the Meervlakte and the Sepik Basin where this mosquito occurs in large numbers.

Culex bitaeniorhynchus and C. annulirostris breed in swamps; their breeding intensity is high when the water contains a small amount of decaying organic matter. One or both species are vectors of importance in several parts of Western New Guinea, as for example Telaga Kokoda villages (de Rook 1957a), Pam Island (de Rook 1957b), and Inanwatan (de Rook 1959; Van Dijk 1961). Culex bitaeniorhynchus is known to be a vector of importance only in the Telaga Kokoda villages.

Iyengar (1959) has grouped the endemic areas of New Guinea under two broad heads: (a) areas where filarial infection is transmitted primarily by mosquitoes of the Anopheles punctulatus group; and (b) areas where the main vectors are culicines. These two sets of areas present certain differences from the point of view of the epidemiology of filariasis.

(a) Areas with filarial infection transmitted primarily by species of the Anopheles punctulatus group.

These include the northern and eastern coastal areas of New Guinea and the coastal areas of the off-shore islands. The principal vectors here are one or more of the three species, Anopheles farauti, A. koliensis and A. punctulatus. In the coastal strip, A. farauti is the most important vector; in the hinterland extensions of the northern littoral the important vectors are A. koliensis and A. punctulatus, the former being of much greater importance in view of its higher numerical prevalence.

The microfilaria rates of the different endemic foci vary considerably, from 2 to 35 per cent. In several foci in the northern littoral microfilaria rates of over 20 per cent have been recorded, as for example Makboen, Saosapor, Saosor, Manokwari and Wariap (north coast of Vogelkop); Wasior, Miei, Koebiari and Sombroko (Geelvink Bay); parts of the districts of Mamberamo, Apauwer, Sarmi, Waris, Madang and Morobe (north coast of New Guinea); hinterland extensions of coastal plains in the districts of Goeay, Kemtuk-Gressie and Nimboran, off-shore islands - Missul, Waigeo, Gam and Salawati, and the south coast of Japen Island.

As the three species primarily concerned in the transmission of filarial infection in these areas are also efficient vectors of malaria, endemic filarial infection co-exists with endemic malaria. In many of the areas, the incidence of filarial infection was found to vary directly as the incidence of malaria (Kariadi 1937; de Rook & Van Dijk 1959). In the foci of Waroppen area, the lower reaches of Mamberamo River, Nimboran valley and the north coast of Vogelkop, high microfilaria rates are associated with high malarial endemicity.

Whereas all areas with endemic filarial infection transmitted by species of the Anopheles punctulatus group are also endemic for malaria, the converse is not true. In numerous areas with endemic or even hyperendemic malaria, W. bancrofti infection is either totally absent, or its incidence is very low. The range of distribution of endemic malaria is much larger than that of anopheline-borne filarial infection. The latter is restricted to foci within a much wider belt of endemic malaria, and in the immediate vicinity of extensive vector breeding sites. As endemic filarial infection could get established only under conditions of intensive transmission of the infection, it occurs only in localities with stable populations, high density of the anopheline vectors, and with extensive vector breeding sites in the proximity of habitations.

Factors of importance in creating facilities for intensive breeding of species of the A. punctulatus group are: (1) extensive clearing of natural forests and jungle, and exposure to sunshine of existing as well as newly made accumulations of water; (2) impounding of water in streams and rivers for agricultural or other purposes; and (3) obstruction to natural ebb and flow of water in tidal channels. Endemic malaria may get established within a comparatively short period of time following such interferences, and may even take an epidemic form. On the other hand, it takes a very much longer period for endemic filarial infection to get established, and only when the community consists of a stable population, and the density of vector mosquitoes is much higher, and their breeding sites are situated much closer to the villages than is necessary for endemic malaria to get established.

In the vast majority of the foci with anopheline-borne filarial infection the incidence of elephantiasis is low. Other manifestations of filarial disease like hydrocele among adult males and lymphangitis are however common. Iyengar (1959) stated: "A remarkable feature of most of the areas (in New Guinea) with anopheles-borne filariasis is the low incidence of elephantiasis. Generally speaking the elephantiasis rates in such areas are rarely higher than 1 per cent, taking all ages into consideration, even though microfilaria rates may be high". Van Dijk (1961) stated that in "areas in New Guinea where only A. farauti occurs as a possible vector of filariasis, filariasis is at most represented by a moderate microfilaria rate among adults without clinical manifestations". In Sagarai valley (Milne Bay area) where A. farauti is the vector and showed a natural infection rate of 15 per cent, and the microfilaria rate in the native population ranged from 35 to 55 per cent, Hopla (1946) observed that the incidence of clinical manifestations of filariasis like lymphangitis and lymphadenitis was surprisingly low.

The reason for the comparatively low incidence of elephantiasis in most of these foci is that conditions are not ordinarily favourable for intensive transmission and for hyperfilariation in man. The density of prevalence of adult mosquitoes of the A. punctulatus group rarely reaches the level attained by culicine vectors. Firstly, the intensity of breeding of anophelines is generally low in comparison with that of culicines. Secondly, extensive breeding sites of the anopheline vectors rarely occur in the immediate vicinity of villages. Such of the potential breeding sites as occur within the villages, or at their periphery, are often rendered unsuitable for the anopheline vectors to breed as a result of organic contamination of the water. These mosquitoes do not breed in polluted water. The distance that separates the actual breeding sites from the villages accounts for the comparatively low density of prevalence of adult mosquitoes in human habitations. The dispersal of mosquitoes from a breeding site varies inversely as the square of the distance, so that mosquito density is low in villages situated at a distance from breeding sites. The farther the breeding site from the village, the greater are the hazards encountered by the female mosquito in her gonotrophic flights between the site of feeding and the site of egg-laying.

Iyengar (1959) discussing the two types of endemic foci in Western New Guinea observed: "The incidence of elephantiasis in areas with anopheles-borne filariasis is low in comparison with areas with culicine-borne filariasis. This is due to differences in the facilities offered for the establishment of hyperfilariation in man. In areas with anopheles-borne filariasis the density of adult prevalence of anopheline vectors rarely reaches the density attained by culicine vectors in areas with culicine-borne filariasis. The intensity of breeding in the larval habitat is usually much lower with anopheline mosquitoes than with culicine mosquitoes. Further the breeding sites of anophelines do not ordinarily occur in the immediate vicinity of habitations. Heavy organic contamination of pools and ditches within the village itself or nearby reduces the breeding density of anophelines because they do not tolerate polluted water.

"On the other hand, in areas with culicine-borne filariasis, the density of adult prevalence of the culicine vectors is often very high. The intensity of larval breeding is high and the breeding sites are often in close proximity to habitations. Quite frequently the habitations are located in the midst of shallow marshes with extensive mosquito breeding all round. In consequence intensive transmission of filarial infection is possible. Intensive breeding in the breeding sites is often facilitated through organic contamination of the water. Dr. de Rook observed that in the Telaga Kokoda Marsh (South Vogelkop area) the breeding of culicine vectors was heavy in, and largely restricted to, the immediate vicinity of the villages and that even at a short distance from the village site the extent of vector breeding was negligible. This is due to organic contamination of the water by excreta and other refuse. This is another example to show how man-made factors favour intensive transmission of filarial infection.

"Because of the high density of culicine vectors and the close proximity of intensive breeding sites to the habitations, intensive transmission is facilitated in areas with culicine-borne filariasis, resulting in hyperfilariation and a high elephantiasis rate in the population. In areas with anopheles-borne filariasis, on the other hand, because of the lower density of vector mosquitoes and because the breeding sites are not so close to habitations, transmission of the infection is less intensive and, in consequence, elephantiasis rates are much lower".

While in the majority of the foci with anopheline-borne filariasis the elephantiasis rates are low, some have high elephantiasis rates, as for example some of the coastal villages on the north coast of Vogelkop, Sombroko in Wandammen, Mamberamo delta villages, and parts of the districts of Waris, Jafi and Kamtuk-Gressie. Information on the vectors in these areas is lacking, although presumably the infection in these areas is carried by anophelines primarily. It is conjectured that in such of the areas within the belt of anopheline-borne filarial infection which have high elephantiasis rates, the primary anopheline vectors are supported by efficient culicine vectors, as it happens in Pam Island. In the absence of such a combination of efficient culicine vectors with vectors of the A. punctulatus group, it seems unlikely that the latter by themselves would be able to maintain a high incidence of elephantiasis in the community.

(b) Areas with filarial infection transmitted primarily by culicine mosquitoes.

These include the southern littoral of New Guinea to the south of the central cordillera, the eastern part of Fak-Fak peninsula, the southern littoral of Vogelkop, and the island of Pam. The important vectors are one or more of the following species: Culex annulirostris, C. bitaeniorhynchus, Mansonia uniformis, Aedes kochi, and Anopheles bancroftii. Culex annulirostris has been found naturally infected with W. bancrofti in Inanwatan, Telaga Kokoda villages, and Pam Island, and

is an important vector in these areas. It is likely that it is a vector of importance in other areas also in view of its high numerical prevalence. Culex annulirostris is "the most prevalent culicine in New Guinea" (Van Dijk 1958a), and surpasses all other species in density of prevalence. Mansonia uniformis is also a widely prevalent species, and in many areas its prevalence is so high as to constitute a pest. It has been found naturally infected in the villages of Telaga Kokoda marsh (de Rook 1957a): it is probable that it is a vector of importance in other parts of the southern littoral, as for example in Bamgi-Ia area (Van Dijk 1958a) and in Upper Digul area. Culex bitaeniorhynchus is an important vector in the interior areas of the southern littoral of Vogelkop, but there is no evidence to show that it is of importance in other parts of New Guinea. Anopheles bancroftii has a wide distribution in the swampy areas in the interior of the main southern littoral; it has been found infected in nature only in the Upper Digul area; it may possibly be of importance as a vector in other areas similar in topography to the Upper Digul, as for example in Meervlakte and Sepik Basin.

Endemic filarial infection has an uneven distribution in the southern littoral. Several extensive areas, as for example the coastal strip and Frederick Hendrik Island, are free from the infection except for sporadic cases. In the other areas, the microfilaria rates vary widely. Elephantiasis rates are often high, over 5 per cent of the total population. Other manifestations of filarial disease like lymphangitis and hydrocele are extremely common.

In the areas with W. bancrofti transmitted primarily by culicines, the incidence of filarial infection shows no relation to the incidence of endemic malaria. Where culicines are the sole vectors malaria is totally absent, as for example Telaga Kokoda villages and Bamgi-Ia area. Where Anopheles farauti is associated with culicine vectors in the transmission of filarial infection, a varying incidence of endemic malaria occurs along with endemic filarial infection, as in Pam Island, Inanwatan, Arguni Bay area and Upper Digul. The incidence of malaria in these areas varies in relation to the local prevalence of the anopheline vector and the proximity of its breeding site to the villages.

Data on the important foci of primarily culicine-borne filarial infection in New Guinea are summarized in Table 5. Some of the foci for which detailed information is available are discussed below.

(i) Telaga Kokoda Villages

The villages in Telaga Kokoda marsh, in the interior of the southern littoral of Vogelkop are examples of foci with W. bancrofti infection transmitted solely by three culicine vectors, Mansonia uniformis, Culex annulirostris, and C. bitaeniorhynchus. These villages are fairly large, with populations of 500 to 1,000, and situated within an extensive, shallow, fresh-water swamp, one to five feet in depth. Each of these villages consists of a large group of

TABLE 5

Endemic foci of primarily culicine-borne filariasis in New Guinea

Foci	Micro-filaria rate	Elephan-tiasis rate	Endemic malaria	Confirmed or probable vectors
Telaga Kokoda villages	21	6	absent	Culex annulirostris C. bitaeniorhynchus and Mansonia uniformis
Pam Island	27	6	present	Anopheles farauti Culex annulirostris and Aedes kochi
Inanwatan	21	5 to 8	present	Culex annulirostris and Anopheles farauti
Arguni Bay area and Kaimana	21 to 24	0.5	present	Culex annulirostris Mansonia uniformis and Anopheles farauti
Bamgi-Ia area	25	1.2	absent	Mansonia uniformis
Upper Digul	25	5.5	present	Anopheles bancroftii A. farauti, Culex annulirostris and Mansonia uniformis

houses, close to one another, and built on piles above the shallow water of the marsh. The water of the marsh in the area of the village is subject to contamination by excreta. Heavy breeding of the three vector mosquitoes occurs in the marsh in the vicinity of the habitations, the organic contamination of the water favouring intensive vector breeding. De Rook's (1957a) observations showed that heavy breeding of these mosquitoes was restricted to the part of the marsh in the immediate vicinity of the villages; very little breeding occurred in the marsh outside of the village area, indicating the importance of organic contamination of the water in favouring intensive vector breeding. Anopheline mosquitoes are totally absent, and the villages are free from endemic malaria.

The density of prevalence of all the three vector mosquitoes in the habitations was found to be very high. In mosquitoes caught from dwelling houses, high rates of natural infection were recorded: Mansonia uniformis, 19.8 per cent; Culex annulirostris, 25.5 per cent; Culex

bitaeniorhynchus, 19.7 per cent (de Rook 1957a). Infective stage larvae of W. bancrofti were present in 1.6, 1.3, and 2.1 per cent respectively in the three species. Under experimental conditions, all the three species showed high hospitability to W. bancrofti, the experimental infection rates ranging between 87 and 94 per cent. Completion of development of the parasite to the infective stage in the experimental infected mosquitoes occurred in $12\frac{1}{2}$ days.

Ideal conditions prevail in these villages for intensive transmission of filarial infection and establishment of hyperfilariation in the human host, namely the occurrence of high density of as many as three efficient vectors, the very close proximity of vector breeding sites to habitations, and a stable population in continuous contact with high vector density. Filarial endemicity is high. The microfilaria rate is 20.8 per cent, and the elephantiasis rate (all ages) is as high as 6.2 per cent. Fifty per cent of the cases of elephantiasis showed multiple lesions; 7.6 per cent of males (all ages) had hydrocele.

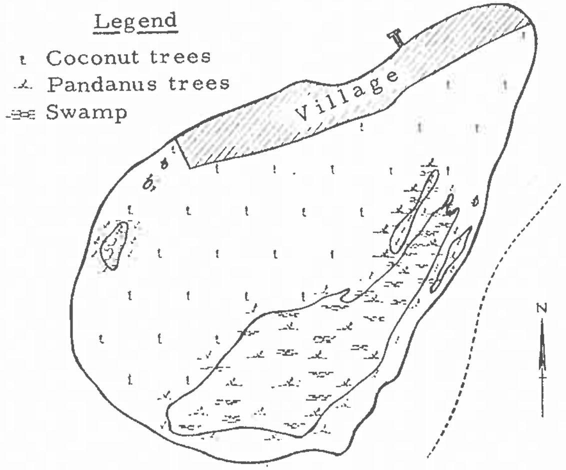
(ii) Pam Island

Pam is a very small island, 1000 metres in length and 600 metres in width (Map 6), situated between Waigeo and Batanta islands in the Dampier Straits at the extreme western tip of New Guinea. The village on Pam (population 250) is situated on the beach along the length of the island on the north. The houses are built on piles over the sea. Practically no mosquito breeding occurs within the village area. To the south of the village is a very extensive swamp in which mosquitoes breed heavily all through the year.

De Rook (1957b) examined the entire population of Pam village; the microfilaria rate was 26.8 per cent, and the elephantiasis rate (all ages), 5.6 per cent; 18 per cent of males of all ages had hydrocele either by itself or in association with elephantiasis of the leg. An interesting feature is the early onset of elephantiasis. De Rook found two girls aged 13 and 14 years respectively, with pronounced elephantiasis of both legs. In Pam, both malaria and filariasis are hyperendemic; de Rook recorded a spleen rate of 100 per cent among school children.

Three species of mosquitoes transmit W. bancrofti in Pam, namely Anopheles farauti, Aedes kochi and Culex annulirostris. Natural infection rates in these mosquitoes were very high. Among mosquitoes caught in habitations, 41, 16, and 7 per cent respectively showed natural infection with developmental stages of W. bancrofti. A large proportion of the infected specimens showed more than a single brood of the parasite. The percentage incidence of mosquitoes with full-grown infective stage larvae of W. bancrofti was 6.6, 1.6, and 2.3 respectively for the three species.

De Rook considers that Anopheles farauti is the primary vector in Pam. An unusually high rate of natural infection (41 per cent) was recorded in this species. The infection rates in the other two vectors,



Pam Island (Western New Guinea) showing location of the village and the marshes breeding vector mosquitoes (from De Rook, 1957, Doc. Med. Geogr. Trop., 9 : 198).

Scale 1 : 10,000

Map 6. Pam Island (West New Guinea)

though much lower than what was recorded in <u>Anopheles farauti</u>, are quite high. Mosquito catches made on human bait at night showed that <u>Aedes kochi</u> was very much more prevalent in Pam village than <u>Anopheles farauti</u>, and that the incidence of <u>Culex annulirostris</u> was about equal to that of <u>A. farauti</u>. The findings, as also the pattern of filarial endemicity, the high incidence of filarial disease, and the early onset of elephantiasis, seem to indicate that the two culicine vectors are at least as important vectors of <u>W. bancrofti</u> in Pam village as is <u>Anopheles farauti</u>.

In the habitations of Pam village all the three vectors occur in large numbers. Extensive breeding sites of these mosquitoes are present within a short distance from the village. <u>Anopheles farauti</u> and <u>Culex annulirostris</u> breed perennially in the extensive swamp which covers a fourth of the area of the island, and lies immediately to the south of the village (Map 6). There is also a profusion of pandanus trees, in the leaf-axils of which <u>Aedes kochi</u> breeds prolifically. The breeding sites of all the three vectors occur close to the village, often at distances of not more than 150 to 200 yards from the habitations. The high density of prevalence of three efficient vectors of <u>W. bancrofti</u>, the proximity of extensive vector breeding sites to habitations, and a stable population in continuous contact with high vector density are factors which favour intensive transmission of filarial infection resulting in the establishment of filarial hyperendemicity in Pam (de Rook 1957b, p. 209).

(iii) <u>Inanwatan Village</u>

In Inanwatan village on the south coast of Vogelkop, filarial hyperendemicity is due to transmission of filarial infection primarily by <u>Culex annulirostris</u>, and secondly by <u>Anopheles farauti</u>. The microfilaria rate of Inanwatan is 21 per cent, and the elephantiasis rate is 5.2 per cent according to de Rook (1959), and 8.4 per cent according to Van Dijk (1961). Van Dijk observed: "The highly endemic filariasis in the Inanwatan area is due to the presence of large numbers of <u>Culex annulirostris</u>. <u>Anopheles farauti</u> acts as a secondary vector, but this species must be considered unable to build up an endemicity of any importance under the prevailing circumstances in Inanwatan, at least without the assistance of other species. In this respect I incline to the assumption that without <u>C. annulirostris</u>, filarial disease would presumably be non-existant or nearly so in Inanwatan" (Van Dijk 1961, p. 155).

(iv) <u>Bamgi-Ia Area</u>

In Bamgi-Ia area situated in the grassy swamp hinterland of the southern littoral of New Guinea, microfilaria rates range between 15 and 31 per cent (average 25 per cent), and the elephantiasis rate is 1.2 per cent. Infection rate in children under 15 years of age is very low, 2.5 per cent. In the later age-groups, however, the microfilaria rate shows an abrupt rise, reaching 55.7 per cent in persons aged 35 years and over. In spite of 39.6 per cent of persons aged

15 years and above showing microfilaraemia, the over-all elephantiasis rate is comparatively low, namely 1.2 per cent, and among persons aged 15 years and over, 2.1 per cent.

Mansonia uniformis appears to be the important vector here (Van Dijk 1958a). Anopheline mosquitoes are virtually absent and malaria is not endemic. In comparison with other areas in New Guinea with filarial infection transmitted primarily by culicine vectors, the elephantiasis rate in Bamgi-Ia area is low (1.2 per cent), in spite of a high density of Mansonia uniformis. This seems to be due to the fact that the villages in this area are not situated close enough to vector breeding sites. Van Dijk stated that these villages are located on undulating land and at considerable distances from the swamps. The location of the villages on land with sensible natural drainage and away from the marshes would explain why the elephantiasis rate in Bamgi-Ia villages is not as high as in Inanwatan, Pam Island, and Telaga Kokoda villages, even though the microfilaria rate is as high as in the latter areas.

(v) Upper Digul Area

In Upper Digul, a densely afforested and swampy area, microfilaria rates are high (25 to 43 per cent according to different observers). The findings on the incidence of elephantiasis are very divergent. De Rook (1930) recorded an elephantiasis rate of 1.0 per cent, while according to more recent observers the elephantiasis rate is quite high, between 5.5 and 7.0 per cent (Van Slooten 1955 & 1956, Van Dijk 1955).

Several species of mosquitoes known to be efficient vectors of W. bancrofti, occur in large numbers in the Upper Digul area, namely Anopheles bancroftii, A. farauti (probably A. koliensis), Mansonia uniformis, and Culex annulirostris. The two culicine mosquitoes occur in large numbers in the endemic foci of this area side by side with the anopheline species (Van Dijk 1958a, p. 31). Definite information on the role of these species in the local transmission of filarial infection is available only for the two species, Anopheles bancroftii and A. farauti. Elsbach (1937) found both of them naturally infected with filaria larvae in Upper Digul. Of these, Anopheles bancroftii is probably the more important vector in view of its high prevalence. De Rook (1930) noted that A. bancroftii outnumbered A. farauti in the proportion of 3 to 1. While A. farauti is restricted in its distribution to comparatively small areas which have been cleared of the dense forest, A. bancroftii occurs in large numbers everywhere, breeding in marshes within the forests as well as in marshes with emergent aquatic vegetation. A high natural infection rate (11 per cent) was recorded by Elsbach in A. bancroftii; under experimental conditions this mosquito was found to be highly hospitable to W. bancrofti, and the development of the parasite to the infective stage occurred within a remarkably short period of time, namely 6 to 8 days. From these considerations, it seems likely that the major vector of

filarial infection in the Upper Digul area is Anopheles bancroftii. No information is available about the role played by Mansonia uniformis and Culex annulirostris in the transmission of filarial infection in Upper Digul. These are confirmed vectors in other parts of the southern littoral, and as they occur in large numbers in this area (Van Dijk 1958a), it is likely that they play an important role in the transmission of filarial infection in Upper Digul as well.

The conditions prevailing in the Upper Digul area, namely the occurrence of a high density of several efficient vectors of W. bancrofti and the presence of extensive perennial vector breeding sites in the proximity of villages, account for the high incidence of filarial disease.

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(2) Bismarck Archipelago

Bismarck Archipelago comprises two large islands, New Britain and New Ireland, and a number of small islands which together ring the Bismarck Sea on the south, east and north. The group includes Feni and Green Islands on the east, Duke of York Islands lying between New Britain and New Ireland, St. Matthias and Admiralty Islands on the north, and the North-western Islands extending as far west as Matty (or Wuvulu) Island. The larger islands are mountainous islands of volcanic origin; the smaller islands are mostly lowlying, flat and of coral origin. The total land area is about 19,200 square miles, and the total population is estimated at 157,000.

New Britain, the largest island of the group with an area of 14,000 square miles and a population of 102,000, is crescent-shaped, 370 miles in length and about 50 miles in width. It is traversed by a high and rugged range of mountains which runs along its entire length. The flat areas are small, and scattered along the coast. Most of New Britain's population is strung out along the coast, or concentrated in a few widely spaced villages at or near the coast. New Ireland, the second largest island of the group, has an area of 3,800 square miles and a population of 38,000. It is a long and narrow island, 200 miles in length and 7 miles in average width. It is traversed by a long mountain range; the coastal plains that fringe this island are very narrow though fairly continuous. All the other islands of the archipelago are small and together have a population of 17,000.

Climate is tropical-oceanic. Temperature and atmospheric humidity are high practically all through the year. Rainfall is heavy, over 100 inches annually; the western part of New Britain receives very heavy rainfall, about 150 inches in the year.

The type of filarial infection endemic in Bismarck Archipelago is the periodic race of Wuchereria bancrofti (Fülleborn 1912). Backhouse and Heydon (1950) demonstrated the periodicity of the microfilaria from studies made in two areas; in Makada the total number of microfilariae in blood smears taken at night from 38 carriers was 2,200, as against a total daytime count of only 26; in Matty, the total microfilaria count in smears taken from 62 carriers at night was 6,330, while the daytime count in smears from the same carriers was 277.

Filarial infection is endemic in the coastal populations of nearly all the islands of Bismarck Archipelago. Data on microfilaria rates based on the examination of night blood samples from representative numbers of persons of all ages are available for only two areas, Makada in the Duke of York group, and Matty in the North-western Islands, where microfilaria rates of 22.7 and 25.3 per cent have been recorded (Backhouse & Heydon 1950). Recorded data in respect to other areas within the archipelago do not give any reliable information as they were based on examinations of small numbers of persons, mostly adult males, and the smears were often taken during daytime.

Cases of filarial disease have been reported to occur on many of the islands of the group. The manifestations are mostly of the milder types, and consist chiefly of lymphangitis, hydrocele among adult males, and less frequently of elephantiasis of the leg. Fülleborn (1912) noted that the distribution of elephantiasis in Bismarck Archipelago was uneven and showed no relation to the incidence of microfilaraemia in the population. He remarked that in some areas the incidence of elephantiasis was high, while in others, cases of elephantiasis were absent even though the microfilaria rates were as high as in those with elephantiasis cases. In a few areas, high elephantiasis rates have been recorded. In Pinepil and Anir, two islands of the Feni group, Kariks and Pike (1954) reported that 3.4 and 3.1 per cent respectively of the total populations of these islands suffered from elephantiasis. According to Backhouse and Heydon (1950) 9.2 per cent of adults in Makada Island had elephantiasis. Except for these few areas with high incidence of elephantiasis, the general incidence appears to be low. Among adult males from various districts of New Britain, 0.7 per cent showed elephantiasis, according to Backhouse and Heydon (1950). In Nyssan and Cartrids, two islands of the Feni group, elephantiasis rates (all ages) are 0.2 and 0.5 per cent respectively (Kariks & Pike 1954). Even in areas with low elephantiasis rates, hydrocele is of common occurrence among adult males; for instance, on Matty Island where no cases of elephantiasis were seen, 11.2 per cent of adult males had scrotal swellings (Backhouse & Heydon 1950).

Two species of the Anopheles punctulatus group, namely A. farauti and A. punctulatus are the vectors of W. bancrofti in Bismarck Archipelago. Anopheles koliensis is not known to occur here. On most of the islands of the group, A. farauti is more prevalent and is the primary vector. A natural infection rate of 25.5 per cent was recorded in A. farauti on Makada Island (Backhouse & Heydon 1950). Both A. farauti and A. punctulatus were found to be very hospitable to W. bancrofti under experimental conditions (Backhouse 1934; Backhouse & Heydon 1950); in both species the experimental infection rates were high, and the infection developed normally to the infective stage. In the Admiralty Islands where A. punctulatus occurs in the absence of A. farauti, the former is the probable vector. As A. farauti and A. punctulatus are also efficient vectors of malaria, a high incidence of endemic malaria occurs in association with endemic filarial infection.

In New Britain, Backhouse and Heydon (1950) found Aedes kochi very hospitable to W. bancrofti under experimental conditions. We have no information as to its importance as a vector in nature. This mosquito has a specialized breeding habitat, and breeds exclusively in water held in the leaf-axils of pandanus trees. It is possible that Aedes kochi may be of importance as a vector in areas where large numbers of pandanus trees occur within, or in close proximity to, villages.

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(3) Solomon Islands

The Solomon Islands comprise 12 islands or island groups stretching out in the form of a double chain from Buka and Bougainville on the north-west to Santa Cruz Islands on the south-east. The larger islands are of volcanic origin, with a mountainous interior and densely wooded. Some of the smaller islands are of coral origin, either atolls (Sikaiana and Ontong Java), or raised coral islands (Rennell and Bellona). On most of the high islands the coastal strip is very narrow. On Bougainville the coastal area is more extensive; along its south-western coast is a large alluvial plain which is marshy in places. On many of the islands there are large swamps at the mouths of rivers. Climate is hot and humid. Rainfall is heavy, on the average 120 inches annually.

The total land area of Solomon Islands is 15,600 square miles, and the total population about 166,000. Average density of population is low, about 11 per square mile. The inhabited areas are mostly along the coast, and the villages are generally located close to mouths of streams. As the streams are torrential in character and dry up during inter-storm periods, many of them are blocked at their mouths to impound the water, and the river water often spreads out to form extensive swamps along the coast.

Schlosser (1945) demonstrated the nocturnal periodic character of the microfilaria of W. bancrofti occurring in the Solomon Islands. The total number of microfilariae in blood smears taken from three microfilaria carriers from the Solomon Islands at different hours of the day, are furnished in Table 6.

Periodic W. bancrofti infection has a wide distribution in the Solomons. The infection is restricted to lowlying coastal areas and is absent in the hilly and undulating areas in the interior. Some of the smaller islands appear to be free from endemic filarial infection, as for example Rennell, Bellona and Anudha (or Cherry) islands. The incidence of the infection varies considerably in the different endemic areas, but comparable data are lacking. Most of the available records refer to samples consisting largely of the adult population, and as such the microfilaria rates would be much higher than, and not representative of, the population as a whole. However, the majority of the islands have low microfilaria rates. In Florida, Sikaiana, Mono and Reef Islands

TABLE 6

Microfilarial periodicity of Wuchereria bancrofti from Solomon Islands (after Schlosser 1945)

Hour	Total number of microfilariae in smears taken from 3 carriers
0900	2
1100	8
1300	17
1500	9
1730	50
1930	262
2130	401
2330	293
0130	507
0530	170

the microfilaria rates are 4 per cent or less. Santa Ana, Ontong Java and Malaita have microfilaria rates of 10 to 12 per cent. In Guadalcanal, San Cristobal and Savo, microfilaria rates are higher than 20 per cent.

The general incidence of filarial disease in the Solomon Islands is very low. In areas with low microfilaria rates, cases of elephantiasis are rare or totally absent. One case of elephantiasis was noted on Sikaiana, and a few on Ontong Java (Black 1952). In Guadalcanal, San Cristobal and Malaita, where microfilaria rates are comparatively high, Byrd and St. Amant (1959) recorded elephantiasis rates of 3.2, 1.2 and 0.8 per cent respectively; these rates are based on the examination of population samples composed largely of adults. From official reports, it would appear that elephantiasis is very common on Bougainville Island, but no information is available regarding the incidence of the disease there.

The major vectors of W. bancrofti in Solomon Islands are Anopheles farauti, A. koliensis and A. punctulatus. Examination of mosquitoes caught from dwelling houses in Guadalcanal showed high incidence of natural infection in A. farauti; 27.7 per cent according to Schlosser (1949), and 51.9 per cent (inclusive of recently ingested microfilariae in midgut) according to Byrd and St. Amant (1959); of 655 specimens of A. farauti examined by the latter workers, a very high proportion (7.9 per cent) carried infective stage larvae of W. bancrofti. A natural infection rate of 15 per cent was recorded in A. punctulatus by Schlosser (1949), and 4.8 per cent in A. koliensis by Byrd and St. Amant (1959). All the three species showed high hospitability to the parasite under conditions of experimental infection.

In parts of the Solomon Islands, Mansonia melanesiensis may play a minor role as a vector of W. bancrofti. Byrd and St. Amant (1959) examined 385 specimens of M. melanesiensis (referred to by these workers as M. uniformis) caught from native huts and found that 6 of them carried larvae of W. bancrofti older than the microfilaria stage, and in three specimens the larvae were 10 to 12 days of developmental age.

As the three major vectors of W. bancrofti in the Solomon Islands are also efficient vectors of malaria, endemic filarial infection occurs in association with endemic malaria. On the two islands with high microfilaria rates, namely Guadalcanal and San Cristobal, malaria is highly endemic, the spleen rates for these areas being 85 and 57 per cent respectively (Levine & Harper 1947).

The breeding sites of species of the Anopheles punctulatus group are sunlit collections of water. Clearing of forests and bush, impounding of water in streams, and interference with flow of water in tidal channels are factors which favour intensive breeding of these mosquitoes. Villages in close proximity to extensive breeding sites of the vector mosquitoes have high microfilaria rates.

To recapitulate, the distribution of endemic filarial infection in Solomon Islands is restricted to lowlying flat areas along the coast. Microfilaria rates are generally low, several small islands being free from the infection. In a few areas, microfilaria rates are comparatively high, as for example Guadalcanal and San Cristobal. Villages situated close to blocked mouths of streams have higher microfilaria rates than those away from vector breeding sites. The general incidence of filarial disease in the Solomon Islands is low, except perhaps in Bougainville Island. Elephantiasis rates for most of the islands are low, less than 1 per cent. The primary vectors of filarial infection are Anopheles farauti, A. koliensis and A. punctulatus. Of these, A. farauti appears to be the most important, being more prevalent than the other two species. As these mosquitoes are also efficient vectors of malaria, endemic filarial infection occurs in association with endemic malaria.

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(4) New Hebrides

The New Hebrides continue south-eastwards the double chain of high mountainous islands represented in the Solomon Islands, and lie between latitudes 12° and 20° S., and between longitudes 165° and 170° E. There are 80 islands in the group, of which about 50 are inhabited. The total land area is 5,700 square miles and the total population about 49,000. The islands of the New Hebrides are of two types: (1) volcanic islands, high and steep, covered with dense high forests, and scored by numerous torrential water-courses; and (2) islands with a volcanic core of lava overlaid with coral limestone, flat topped, with precipitous sides and comparatively few streams, and not densely afforested. The coastal strip is narrow, often scattered and discontinuous. The coastal settlements are mostly located at mouths of streams, many of which are blocked by sand or shingle bars. Rainfall is about 85 inches annually. Both rainfall and average temperature are higher in the northern part of New Hebrides than in the southern part.

Endemic filarial infection in the New Hebrides consists of the periodic race of Wuchereria bancrofti. From an examination of night and day blood samples from 46 carriers, Buxton (1927) showed that the microfilaria in the New Hebrides exhibited characteristic nocturnal periodicity. The total microfilaria count in blood smears taken at night by Byrd and St. Amant (1959) from 26 carriers from New Hebrides was 2,659, while the total count in smears taken during daytime from the same person was only 62.

Filarial infection is widespread in the group. Nearly all available data on the incidence of W. bancrofti infection in the different islands of New Hebrides are based on the examination of adult male populations, and often only of small numbers of persons. The microfilaria rates vary widely in different parts of the group. In the northernly islands, microfilaria rates (for adult males) are higher than 30 per cent, as for example Torres Islands, Banks Islands, Espiritu Santo, Aoba, Maewo, Pentecost, Malekula and Epi. The islands in the southern part of New Hebrides have very low microfilaria rates. Some of the islands, e.g., Araki, Tongoa and Futuna, appear to be free from endemic filarial infection.

Although filarial infection is widespread in New Hebrides, and microfilaria rates are often high, the general incidence of filarial disease is very low. Buxton (1927) observed that individuals with large numbers of microfilariae in the blood but without any signs of filarial disease were even more common in New Hebrides than in Western Samoa; and yet the incidence of filarial disease was very low. The manifestations of filarial disease in New Hebrides consist mainly of elephantiasis of the leg or scrotum, and hydrocele. Cases of hydrocele are however of more frequent occurrence than cases of elephantiasis. Buxton (1928) recorded 23 cases of hydrocele among 292 males (16 years of age and over) examined by him from different islands of New Hebrides. Generally, the manifestations of filarial disease are of the mild type. Gross manifestations are very rare. Buxton (1927) remarked that filariasis in New Hebrides is not clinically grave. "The cases of elephantiasis which I saw were, nearly all of them, very slight and confined to the scrotum; most of them would have remained undetected without a systematic examination" (Buxton 1927, p. 236).

In the vast majority of the islands of New Hebrides, elephantiasis rates are extremely low. Davies (1951) carried out a detailed examination of a very large number of persons of all ages, totalling over 21,000, from most of the islands of the New Hebrides. His findings, reproduced in Table 7, furnish reliable information on the incidence of elephantiasis in the different islands of the New Hebrides. In many of the islands, the elephantiasis rate is zero, as for example Nguna, Pele, Mau, Mataso, Tongariki, Tongoa, Futuna, Aneityum, Tanna, Laman, Paama, Lopevi, Ambrym, Malo and the Banks group. In four islands, namely Efate, Epi, Aoba and Marelava, elephantiasis rates are very low (0.1 to 0.2 per cent). In a few areas, as for example Aniwa, Pentecost, Maewo, Erromanga, Malekula and islands off the coast of Malekula, elephantiasis rates are slightly higher, between 0.8 and 1.3 per cent. Comparatively high elephantiasis rates were recorded from only two areas, Espiritu Santo and Torres Islands (2.6 and 2.9 per cent respectively).

Recent researches have confirmed Buxton's (1927) conclusions, based on epidemiological evidence, that Anopheles farauti is the vector of periodic W. bancrofti in New Hebrides. Buxton stated: "We do not at present know which species of mosquito carries the filariasis of the New Hebrides, or indeed of any part of Melanesia. The carrier cannot be Culex fatigans, which is a recent importation only known from Vila. Though actual experimental work has yet to be done there is epidemiological evidence which bears on the subject. In general there is a coincidence between the distribution of malaria and of filariasis in the group. Apparently both diseases occur in all parts of the New Hebrides, except that both are absent from Futuna. One concludes that possibly the carrier of filariasis in the New Hebrides is Anopheles punctulatus" (Buxton 1927, p. 235).*

Byrd and St. Amant (1959) from an examination of 1,239 specimens of A. farauti caught from dwelling houses determined a natural infection rate of 13.7 per cent in this mosquito. All stages of development of the parasite were seen in the infected specimens, and a high proportion of them carried infective stage larvae. In New Hebrides, which forms the extreme south-easterly limit of the range of distribution of anophelines mosquitoes in the South Pacific, A. farauti is the only anopheline species present. As A. farauti is also the vector of malaria in New Hebrides, filarial infection occurs co-endemically with malaria as has been observed in most other parts of the Papuan zone. Buxton (1927) noted that there was a coincidence between the distributions of malaria and filarial infection in the New Hebrides. Endemic malaria however has a much wider

* The species referred to as Anopheles punctulatus by Buxton (1927) is Anopheles farauti, the only species of Anopheles occurring in the New Hebrides.

TABLE 7

Elephantiasis rates (all ages) of the different islands of the New Hebrides (after Davies 1951)

Island	Number examined	Elephantiasis rate
Efate	1,250	0.2
Nguna & Pele	581	0.0
Mau	290	0.0
Mataso	86	0.0
Tongariki	126	0.0
Tongoa	1,039	0.0
Futuna	250	0.0
Aneityum	206	0.0
Aniwa	114	0.9
Erromanga	240	1.3
Tanna	1,252	0.0
Malekula, Norsup, Vao, Achin, Wala, Rano, Uripiv, Uri and Kulivu	4,256	1.1
Laman	178	0.0
Paama	1,042	0.0
Lopevi	137	0.0
Ambrym	1,591	0.0
Pentecost	2,133	0.8
Epi	660	0.2
Santo	1,245	2.6
Malo	253	0.0
Aoba	2,076	0.05
Merelava Banks	556	0.2
Mota Banks	148	0.0
Motalava Banks	365	0.0
Vanua Lava Banks	258	0.0
Gaua Banks	117	0.0
Ureparapara Banks	58	0.0
Torres (Toga, Lo & Hui)	102	2.9
Maewo	475	0.8

range of distribution in New Hebrides than endemic filarial infection. The latter is largely restricted to villages situated close to permanent breeding sites of A. farauti.

Anopheles farauti breeds in water collections exposed to sunshine; it has a wide range of breeding habitats, - fresh or brackish water, permanent swamps or temporary pools. The permanent breeding places of A. farauti are lagoons formed at the mouths of streams blocked by sand bars.

Because the stream provides a supply of water, villages and settlements are often sited near blocked mouths of streams.

The occurrence of extensive breeding places of A. farauti in the vicinity of habitations is the important factor which determines filarial incidence. This is brought by Byrd and St. Amant (1959) who made a comparative study of two villages close to one another on the island of Espiritu Santo, - Wailapi, a coastal village situated close to permanent breeding sites of A. farauti, and Narango village, atop of a 700-foot ridge. The microfilaria rates of the two villages are markedly different, 31.1 per cent in Wailapi, and 2.5 per cent in Narango. The two villages do not differ in regard to the prevalence of the vector mosquito, A. farauti. Vector density is equally high in both villages, and sometimes even higher in Narango than in Wailapi. In some of the huts of Narango village, vector density was found to be as much as 500 per man-hour. On the other hand, very different results were obtained from the examination for filarial infection of adult mosquitoes collected from habitations in the two villages. In Wailapi, 34.3 per cent of A. farauti caught in houses harboured larvae of W. bancrofti in various stages of development. Many of the infected specimens showed full-grown filaria larvae of the infective stage, indicating that transmission of filarial infection occurred in Wailapi. In Narango, only 7.1 per cent of A. farauti caught from habitations proved to be positive, but none of the infected specimens harboured any stages of the parasite older than the freshly ingested microfilaria within the midgut of the mosquito. There was no evidence of transmission of filarial infection happening in Narango.

These two villages, although close to one another, and with equally high vector density, differ very markedly in respect to filarial endemicity. The microfilaria rate of Wailapi village situated in the proximity of extensive vector breeding sites is 31 per cent; in Narango situated at a distance from vector breeding sites the microfilaria rate is 2.5 per cent. Active transmission of filarial infection occurs in Wailapi as evidenced by the high infection rate (34.3 per cent) in the vector and the occurrence of infective stage larvae of W. bancrofti in many of the infected specimens. Although in Narango 7 per cent of A. farauti caught in houses showed infection with W. bancrofti, none of the infected specimens harboured stages older than the microfilaria in the midgut of the mosquito, indicating that conditions are not favourable for transmission of the infection in Narango. These observations demonstrate the fact that active transmission necessary for the establishment of high filarial endemicity could happen only where vector breeding sites occur close to habitations.

Buxton (1927) showed that the abundance of vector breeding sites near villages has an important bearing on the local filarial endemicity. Two adjacent areas on the island of Espiritu Santo differ markedly in regard to abundance of surface water. The western part of Santo is plentifully watered by streams, many of which are dammed at the mouth by sand bars. Surface water, both running and stagnant, is abundant. The eastern

part, on the other hand, has little of surface water. "The whole of east Santo is a plateau of raised coral, about 600 feet above sea level, almost entirely devoid of surface water, except after heavy rains; between Turtle Bay and a point about one mile east of the mouth of the River Jordan, that is to say, along more than 60 miles of coast-line, not a single stream enters the sea. The rainwater, about 100 inches a year, sinks into the coral limestone, and only reaches the surface in a series of seepages just below high-tide mark. West Santo, on the other hand, including that part of Big Bay which lies west of the River Jordan, is volcanic; this part of Santo is certainly provided with great abundance of surface water. Streams pour down the hills in every direction; many of them are blocked by shingle bars at the mouth and spread out into stagnant swamps; swamp taro is grown by damming the streams and making small ponds" (Buxton 1927, p. 232).

Opportunities for the breeding of Anopheles farauti are plentiful in the inhabited areas of West Santo, and very poor in those of East Santo. The two areas differ very markedly in the incidence of filarial infection and of filarial disease as shown by the data presented in Table 8 (after Buxton 1928, p. 60).

TABLE 8

Incidence of filarial infection, hydrocele and elephantiasis among males (over 20 years of age) of the villages of West Santo and East Santo (after Buxton 1928)

Area	Number examined	Microfilaria rate	Hydrocele rate	Elephantiasis rate
West Santo	50	68.0	20.0	24.0
East Santo	39	20.5	5.1	0

The microfilaria rate, the hydrocele rate and the elephantiasis rate among adult males of West Santo villages are high, 68, 20 and 24 per cent respectively; the corresponding rates for East Santo villages are 20.5, 5.1 and zero per cent respectively. Even in regard to intensity of infection in the microfilaria carriers, the two areas differ markedly. In East Santo, none of the 8 persons found to be positive for microfilaria in peripheral blood, showed a microfilarial density higher than 30 per 20 cmm. (Buxton 1928, p. 62); in 7 of the 8 positives, the density was very low, ranging between 1 and 20 per 20 cmm. In West Santo, on the other hand, 18 of the 34 positives showed microfilaria counts higher than 50 per 20 cmm. of blood, and in 8 cases the counts were higher than 100. Judged by each of the criteria, the microfilaria rate, the intensity of filarial infection in the carriers, the hydrocele rate, and the elephantiasis rate, West Santo has a very much higher filarial endemicity than East Santo.

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IX. POLYNESIAN ZONE

(1) Fiji Islands

Geographically, faunistically, and from the point of view of the epidemiology of filariasis, Fiji forms part of the Polynesian zone, although the Fijians belong to the Melanesian race.

The Fiji Islands lie between latitudes 15° and 22° S., and between longitudes 175° E. and 177° W. They comprise about 300 islands, of which 105 are inhabited. The total land area is roughly 7,040 square miles. Four large islands in the central part of the group together constitute 90 per cent of the total land area of Fiji, namely Viti Levu (4,011 sq.m.), Vanua Levu (2,137 sq.m.), Taveuni (168 sq.m.), and Kandavu (158 sq.m.). All the other islands are small and fall under three groups, the Lau group on the east, the Lomaiviti group at the centre, and Yasawa group on the north-west. Physically the islands of Fiji, with the exception of a few coral islands, are high islands of volcanic origin. The mountainous areas as well as the fertile valleys are covered with dense tropical vegetation.

The climate of Fiji is tropical-oceanic. There is no seasonal variation of temperature. Mean temperature is about 78° F. Atmospheric humidity is high, generally over 80 per cent. Rainfall is heavy, ranging from 70 to 130 inches annually in different parts of the group. Rainfall occurs practically all through the year, and there is no distinct dry season. On the larger islands there is marked difference in the amount of rainfall of the windward (eastern and south-eastern) side which is very wet, and the leeward (western and north-western) side which is comparatively dry.

The total population of Fiji is about 370,000. On the larger islands there are several areas with urban and quasi-urban concentration

of population. Besides the large town of Suva with a population of 37,000, there are many small townships. Other than these, the populations are typically rural and largely restricted to the flat coastal areas.

Filarial disease has long been known to be very prevalent in Fiji. Messer (1876) reported that elephantiasis was very common among the Fijians, especially in the populations of lowlying swampy areas. Even Europeans were found to be affected with the disease. Messer mentioned that two Europeans who had been resident in Fiji for 5 and 15 years respectively had developed elephantiasis of the leg. Finucane (1901) stated that elephantiasis was prevalent in all the islands of the Fiji group, and although all races were affected, Fijians suffered commonly from it. Among males the scrotum was the part most commonly affected; among females, elephantiasis of the leg, arm and breast was very common. The disease was noted to occur in a virulent form in the lowlying swampy districts, such as the Rewa delta and the coastal areas of Ra Province. Finucane observed that filarial lymphangitis was extremely common, and that even young children suffered from periodical attacks of filarial lymphangitis; he stated that most Fijians were liable to as many as four to five such attacks annually. De Boissière (1904) stated that filarial disease was very common in Fiji, especially in Bua (Vanua Levu Island), and that it was exceptional to find a Fijian who was not subject to one form or other of filarial disease. Brunwin (1909) reported that a large proportion of the Fijians suffered from elephantoid affections. In the islands of the Lau group, elephantiasis is known to be very prevalent. Bahr (1912) observed that 6.8 per cent of the total population of Lakemba Island in the Lau group had elephantiasis; the elephantiasis rate for two other islands of the same group, namely Vanua Balavu and Oneata, was comparatively lower, 1.8 per cent. Amos (1953) reported that the distribution of elephantiasis in the Fiji Islands is uneven; the disease is common only in certain areas, such as the islands of the Lau and Lomaiviti groups and in Vanua Levu Island. In the major part of Viti Levu Island, the incidence of the disease is reported to be very low, as also in the islands to the south of Viti Levu, with the exception of Mbengga where an elephantiasis rate of 2.7 per cent was recorded (Report, Fiji Medical Department, 1952-53). Knott (1944) stated: "The disease (elephantiasis) is very prevalent in the small coconut growing islands but is not common on the large sugar-cane growing islands". Nelson and Cruikshank (1956) examined nearly 58,000 persons of 5 years of age and over from different parts of Fiji and determined the over-all elephantiasis rate as 0.9 per cent.

Other manifestations of filarial disease like lymphadenitis, lymphangitis and hydrocele are of more frequent occurrence than elephantiasis. In many areas the incidence of hydrocele among adult males was found to be very high. In Bau, an island at the mouth of the Rewa River (Viti Levu), although no cases of elephantiasis were present, 17.3 per cent of adult males had hydrocele (Bahr 1912); in Lakemba and Oenata, two islands of the Lau group, 12.7 and 19.4 per cent respectively of adult males had hydroceles.

Non-periodic W. bancrofti infection has a wide distribution in Fiji. High microfilaria rates, 25 to 33 per cent, were recorded by Bahr (1912) in the islands of the Lau group. According to Nelson and Cruikshank (1956), the microfilaria rates for the different areas on Viti Levu Island range from zero to 44 per cent, and on Taveuni Island, from 20 to 30 per cent; the windward wet side of Vanua Levu Island has very much higher microfilaria rates (range 22.9 to 26.6, average 24.7 per cent) than the leeward dry side (range 1.4 to 14, average 7.5 per cent). Symes stated that "the areas with heavier rainfall and denser vegetation-cover appear to be those with higher incidence of filariasis". Knott (1944) observed that filarial infection was rare in the dry western part of Viti Levu Island. Urban and quasi-urban areas are practically free from endemic filarial infection; Brunwin (1909) remarked that filariasis is rare in Suva.

The important vectors of W. bancrofti in Fiji are two species of the Aedes (Stegomyia) scutellaris group, namely A. polynesiensis and A. pseudoscutellaris (Manson-Bahr 1955; Burnett 1960). These mosquitoes have a wide distribution in Fiji. Amos (1953) noted that vector density varied considerably in the different areas depending on the opportunities offered for Aedes breeding, and that the microfilaria rate in the population varied in direct relation to local vector density. He mentioned that in areas with poor facilities for vector breeding, the microfilaria rate was low; where conditions favoured intensive vector breeding, the microfilaria rates were high. Bahr (1912) observed that filarial endemicity was high in the islands of the Lau group where an extremely high density of Aedes polynesiensis prevailed.

The important breeding sites of Aedes are domestic containers for storing rain-water, coconut shells and discarded tin-cans. In many areas, as in the islands of the Lau group, the people depend on collected rain-water for their supply of fresh water; domestic containers for storing rain-water constitute the perennial breeding sites for these mosquitoes. The presence of large numbers of such containers in practically each household accounts for the high vector density in the village areas. Of the temporary breeding sites of Aedes polynesiensis, the rat-damaged coconut is the most important (Nelson & Cruikshank 1956). Rats cause considerable damage to the coconut crop on many islands of the Fiji group. Paine (1935) estimated the economic loss of coconut crop through rat damage on Taveuni Island as at least 28 per cent. In the islands of the Lomaiviti and Lau groups, the extent of damage to coconuts caused by rats appears to be much greater. In these islands the villages are located in the midst of coconut plantations heavily infested with rats. The profusion of rat-damaged coconuts in the vicinity of habitations would account for the high density of Aedes in the inhabited areas and for the high filarial endemicity.

Symes (1955) recorded the finding in Viti Levu of natural infection with filaria larvae in several species of mosquitoes besides Aedes polynesiensis and A. pseudoscutellaris, namely Culex fatigans, C. annulirostris, Aedes (Finlaya) fijiensis, and Aedes (Aedimorphus) vexans. In all of them

Symes found full-grown filaria larvae, presumably of W. bancrofti. The natural infection rates recorded by Symes in C. fatigans, C. annulirostris and A. fijiensis were very much higher than what was recorded in the two confirmed vectors, A. polynesiensis and A. pseudoscutellaris. Under experimental conditions, C. fatigans and A. fijiensis were stated to be as hospitable to non-periodic W. bancrofti from Fiji as A. polynesiensis and A. pseudoscutellaris. It was stated that "mature infections" were found in 43 out of 90 C. fatigans experimentally fed on microfilaria carriers, and in 40 out of 47 A. fijiensis. Symes expressed the view that C. fatigans and A. fijiensis are as important vectors of W. bancrofti in Fiji as are A. pseudoscutellaris and A. polynesiensis.

Symes' findings in respect to C. fatigans are at variance with those of other workers. Manson-Bahr and Muggleton (1952) stated that C. fatigans is "an incompatible host to the non-periodic Fijian microfilaria". Epidemiological evidence is against accepting Symes' view that C. fatigans is a vector of importance in Fiji. Most of the areas with high incidence of endemic filarial infection have extremely low prevalence of C. fatigans; in urban and quasi-urban areas where the incidence of this mosquito is very high, there is little of endemic filarial infection. Brunwin (1909) also remarked that Culex fatigans "is found often in considerable numbers in Suva, where filarial infection never takes place".

Both Symes (1955) and Burnett (1960) have recorded natural infection with filaria larvae in Aedes fijiensis. There is however little epidemiological evidence to show that this mosquito plays an important role in the transmission of W. bancrofti in Fiji. It is not a common mosquito in the areas with high filarial incidence. As this mosquito has a specialized breeding habitat and breeds exclusively in the water held in the leaf-axils of pandanus trees, it has a very restricted distribution. However, in localities where large numbers of pandanus trees occur in the vicinity of habitations, it is possible that A. fijiensis may play a secondary role in the transmission of filarial infection. Available information seems to support the view that the major vectors of W. bancrofti in Fiji are A. pseudoscutellaris and A. polynesiensis.

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(2) Tonga Islands

Tonga Islands lie between latitudes 15° and 23° S., and between longitudes 173° and 177° W. There are about 150 islands in the group, most of which are uninhabited; the total land area is 256 square miles. The islands are disposed in three widely separated clusters, Vavau group on the north, Tongatapu group on the south, and Haapai group in the middle. The Haapai and Tongatapu groups consist of low islands of coral origin; the islands of Vavau are of volcanic origin, rising to heights of 300 to 600 feet. Along the westerly limit of Tonga is a long chain of small volcanic islands, on some of which active volcanoes exist.

The total population of Tonga is about 58,000, of which nearly half live in the Tongatapu group, and about 16 per cent in Vavau; the other inhabited islands of the group have small populations, for the most part only a few hundreds in each.

The northern part of Tonga has a tropical-oceanic climate; in the southern part the climate is sub-tropical. Rainfall is fairly well distributed over the year and averages about 80 inches annually. Rain-water collected from roofs of houses is the source of drinking water. Nukualofa, on Tongatapu Island, is provided with a piped water supply. During recent years, concrete tanks for rain-water have been erected in many villages, using roofs of public buildings as catchment.

Filarial disease has long been known to be very prevalent in Tonga. In Captain Cook's notes on his voyage in the South Pacific during the middle of the 18th century, mention is made of the common occurrence of enormous swelling of the leg and arm as also of the scrotum among the natives of Tonga (Cook 1785). During the 19th century, Saffre (1884),

Manson (1896), and Thorpe (1896) noted that elephantiasis was very common in Tonga, and that the parts most commonly affected were the leg and the scrotum. Leber and Prowazek (1914) noted the occurrence of endemic cases of elephantiasis in Niuafoou, a small island to the north of the Vavau group. Recent official reports state that filarial disease is a major public health problem in Tonga. The general incidence of elephantiasis seems to be high, although reliable data in respect to most of the islands are not available. A recent survey by Tapa (1957) in Niuatoputapu, a small island in the northern part of Tonga, shows that 7.6 per cent of the total population of that island are affected with elephantiasis.

Even in regard to the incidence of filarial infection in the different islands of the group, we lack precise information. Tonga carries the distinction of being the place where the non-periodic race of W. bancrofti was discovered by Thorpe (1896). Based on the examination of adults, Thorpe recorded microfilaria rates of 20 to 47 per cent in four islands of Tonga; Nomuka and Lifuka (Haapai group) 28.8 and 46.9 per cent respectively; Vavau, 20 per cent; Tongatapu, 29.2 per cent. Hopkins (1925) examined small numbers of boys and young men from different parts of Tonga then residing at the college in Tongatapu; the microfilaria rates among them were as follows: Tongatapu 13.5 per cent; Haapai 14.3 per cent; Vavau 46.2 per cent. More recent information on the incidence of filarial infection in Tonga is based on the examination of hospital patients. During 1953 to 1956, Tapa (1957) examined fairly large numbers of hospital patients in the Vaiola Hospital in Tongatapu and found that 28.2 to 48.5 per cent carried microfilariae; of 345 patients examined in Ngu Hospital, Vavau, during 1956, 49.6 per cent were positive for microfilariae in peripheral blood.

On epidemiological grounds, Buxton (1927) conjectured that Aedes tongae, a member of the Aedes (Stegomyia) scutellaris group, is the vector of W. bancrofti in Tonga. Buxton's surmise has recently been proved to be correct; Ramalingam and Belkin (1964) working in Tongatapu observed that 5.8 per cent of A. tongae showed natural infection with larvae of W. bancrofti, and that 66.7 per cent of specimens of this species took the infection under experimental conditions.

Aedes tongae, which has a distribution restricted to Tonga, occurs widely in all the three island clusters of the group, Vavau, Haapai and Tongatapu. In many areas it occurs in large numbers. Like the allied species A. polynesiensis, A. tongae is a day-biting mosquito and breeds in rain-water containers, coconut shells, tin-cans and tree-holes. In the vicinity of human habitations, plentiful opportunities are offered for A. tongae to breed. Every house has several containers for storing rain-water which breed this mosquito practically all through the year, and in addition there are numerous small containers like coconut shells and tin-cans lying about in bush close to habitations, the extent of Aedes breeding in which varies according to the amount of rainfall. The writer observed that the density of A. tongae in the vicinity of habitations even in well developed areas of Tongatapu and Vavau islands was high.

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(3) Rotuma

Rotuma is a small isolated group of high islands of volcanic origin, situated about 240 miles north of Fiji, at latitude 12° 30' S., and longitude 177° E. The total land area of the group is 18 square miles. Nearly the entire population of the group lives on Rotuma, the principal island. The 8 small islets that surround the island of Rotuma are uninhabited, except that there is a small village on Uea islet. Rotuma island is 8 miles long and 2½ miles in width at its widest part, with a rugged mountainous interior rising to peaks 700- to 800-feet high. The sprawling villages are located on the narrow coastal strip, mostly in the western part of the island, the hilly areas in the interior being uninhabited. The total population of Rotuma is about 4,300. The Rotumans belong to the Polynesian race. Rotuma has a fertile soil; coconuts, tropical fruits and vegetables grow well. Copra making is the principal industry.

Rotuma has a hot and humid climate. Rainfall is heavy, over 100 inches annually. There are no streams on Rotuma. There are a number of wells in the villages but as they are close to the beach the water in them is brackish and not fit for drinking. Collected rain-water is the only source of fresh water. Rain-water is stored in a variety of domestic containers like drums, barrels, buckets and tins. Every house has several such containers for storing water. In Itumuta, a small area in the western part of the island, three tiny villages are provided with piped water supply drawn from a well at the foot-hills in the interior, but the supply is very inadequate. Even in these villages the people have to collect rain-water and store it in containers.

Filarial disease is known to be very common among the inhabitants of Rotuma. As early as 1896, Rotuma had the reputation of being a "hot-bed of elephantiasis" (Thorpe 1896). Brunwin (1909) stated: "In Rotuma nearly all the inhabitants seem to be affected, white as well as native". Lambert (1929) examined 2,020 persons on Rotuma and found 185 of them with clinical signs of filarial disease (excluding enlargement of epi-trochlear glands); there were 29 frank cases of elephantiasis (20 of the leg, 7 of the arm and 2 of mammae), giving an elephantiasis rate of 1.4 per cent for the total population. Lambert remarked that a striking feature of filariasis in Rotuma was the high frequency of occurrence of genital affections in the male, such as elephantiasis of the scrotum; hydrocele and filarial affections of the epididymis. Amos (1946) determined the elephantiasis rate of Rotuma as 2.1 per cent; he examined over 1,900 persons. According to Nelson and Cruikshank (1956) the elephantiasis rate for Rotuma is 3.5 per cent; they examined 2,700 persons.

Lambert (1929) showed that the type of infection occurring in Rotuma is the non-periodic W. bancrofti. The microfilaria rate as determined by Lambert was 28.7 per cent (171 persons examined). Amos (1946) from an examination of 1,938 persons of all ages in Rotuma recorded a microfilaria rate of 20.8 per cent. Of 1,068 school children aged 5 to 19 years examined by Amos, 6.8 per cent were positive for microfilaria in peripheral blood (5.7 per cent of male children, and 7.9 per cent of female children); The incidence of filarial infection among these children showed a progressive rise with increasing age; 5 to 9 years, 4.2 per cent; 10 to 14 years, 8.2 per cent; and 15 to 19 years, 9.8 per cent.

No studies have been carried out to determine the vector of non-periodic W. bancrofti in Rotuma. Epidemiological evidence indicates that the vector here is Aedes (Stegomyia) rotumae, the only species of the Aedes scutellaris group occurring in Rotuma. Like its close ally, A. polynesiensis, A. rotumae breeds in artificial containers like barrels and drums for storing water, coconut shells and tin-cans.

It was mentioned earlier than the people of Rotuma depend on collected rain-water for their supplies of fresh water. Even in the three small villages in Itumuta which are served with piped water supply, the supply is so meagre that the people have to maintain domestic receptacles for storing rain-water. As these containers are not provided with proper lids, Aedes breeds in large numbers in most of them. The incidence of Aedes breeding in these containers was noted to be very high, ranging from 47 to 100 per cent in different village areas. Another factor favouring a high prevalence of Aedes rotumae in the village areas of Rotuma is the profusion of litter capable of holding rain-water, such as tin-cans and coconut shells. A common practice is to throw domestic refuse into scrub at the back of houses (Amos 1946). The litter includes among other things, large numbers of discarded tin-cans, coconut shells, and shells of coconuts opened for the water contained in them. A common drink of the Rotuman is the water in tender coconuts. The high incidence of adult Aedes rotumae in the village areas of Rotuma is due to the presence of numerous domestic water containers and the profusion of coconut shells which are constantly kept filled with water by the heavy rainfall. The high vector density in the inhabited areas and the proximity of breeding sites to habitations account for the high filarial endemicity in Rotuma.

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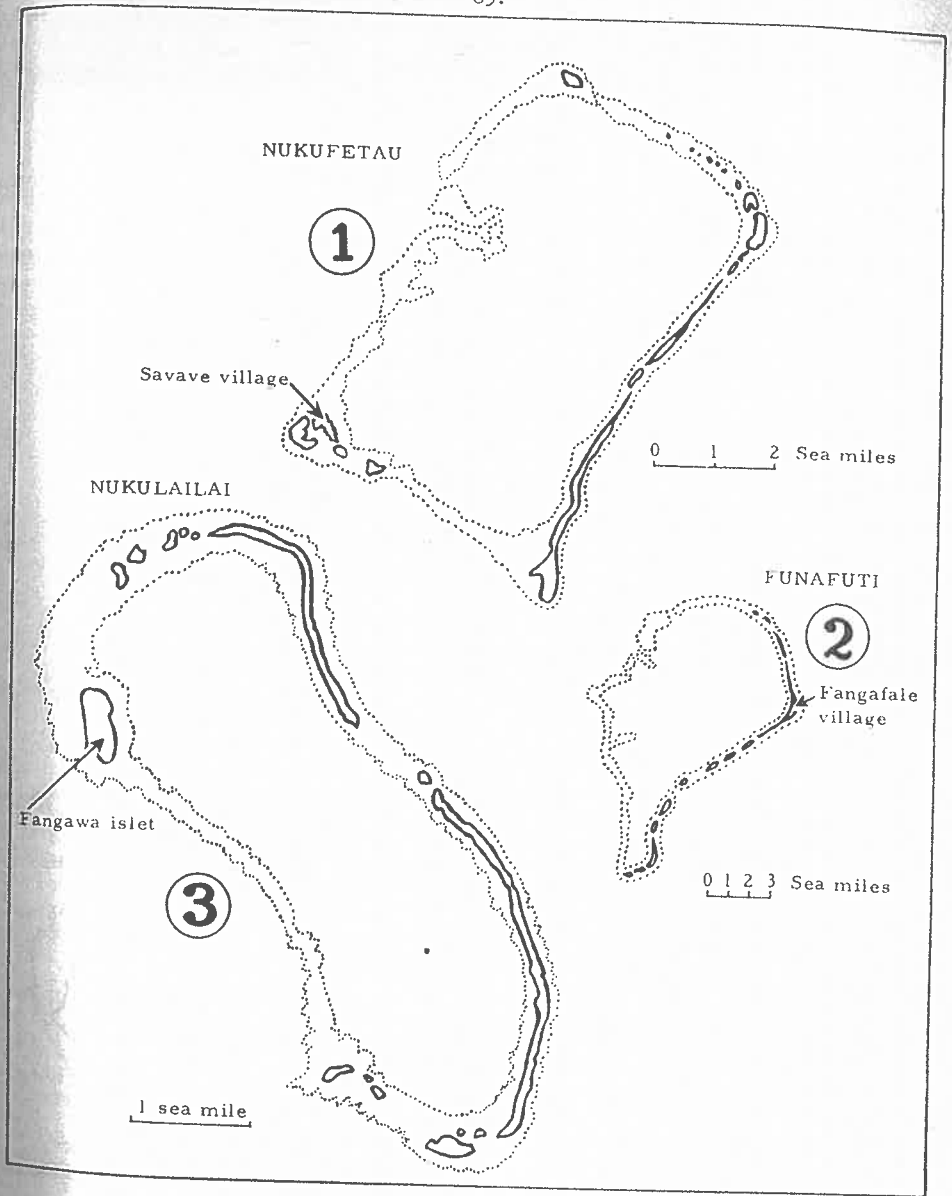
(4) Ellice Islands

The Ellice Islands lie to the south of the Gilbert Islands, separated from the latter by an ocean gap of about 200 miles. The group is situated between latitudes 6° and 11° S., and between longitudes 176° and 180° E., and consists of a chain of 9 islands of coral origin, namely Nanumea, Niutao, Nanumanga, Nui, Vaitupu, Nukufetau, Funafuti, Nukulailai and Nurakita. The distance from Nanumea, the northernmost island, to Nurakita, the southernmost, is about 300 miles. All the islands of the group are small, lowlying, and not higher than 20 feet above sea level. Their total land area is only 10 square miles.

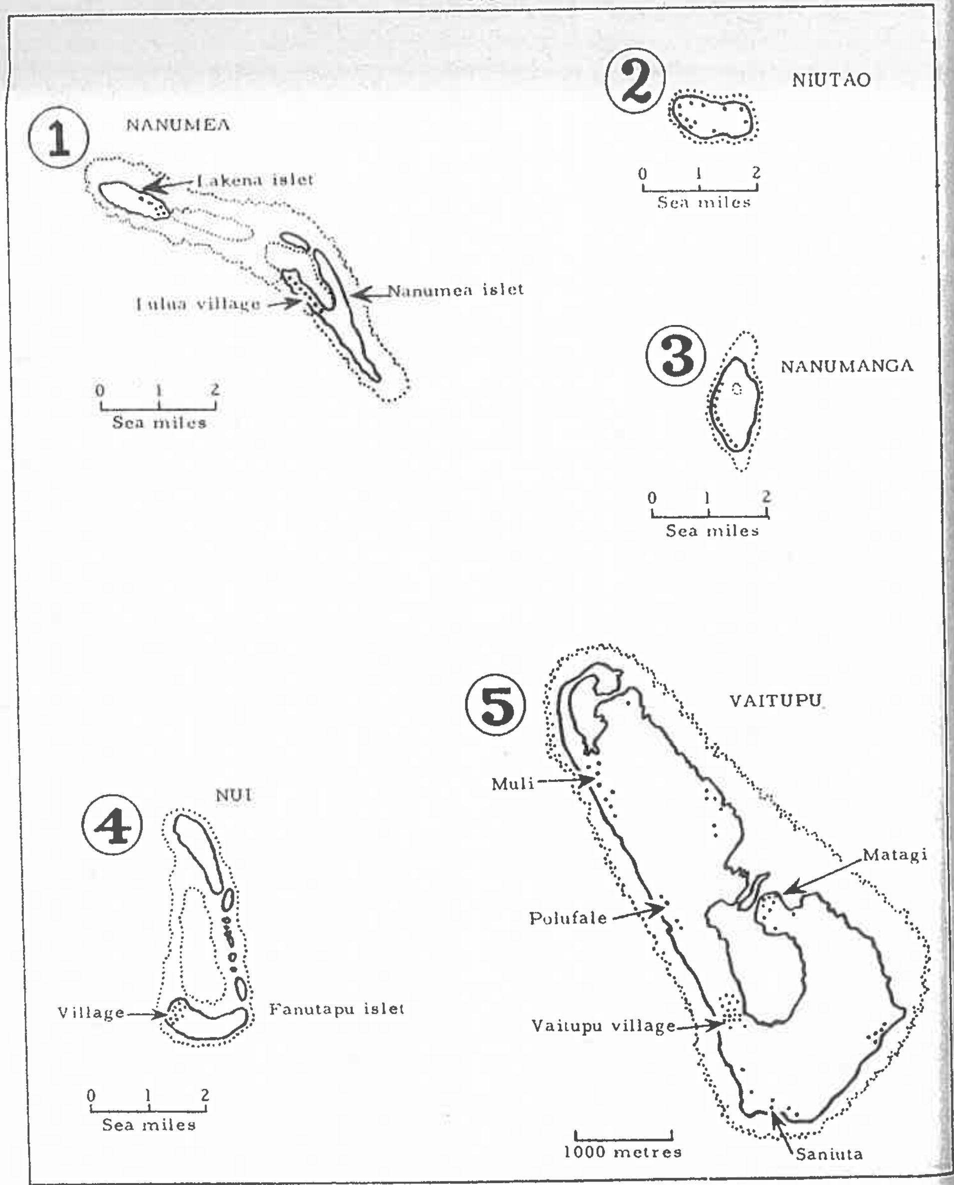
Eight to the nine islands are inhabited; Nurakita has no permanent population. The total population of the group is 5,000. The populations of the different islands range from 500 to 900, excepting Nukulailai which has a population of only 260. The Ellice Islanders belong to the Polynesian race.

The climate of the Ellice Islands is tropical-oceanic, with little seasonal variation in temperature. Mean temperature ranges between 78° and 80° F. Diurnal variation in temperature is small. Atmospheric humidity is very high all through the year. Rainfall is plentiful, averaging about 100 inches annually. The southerly islands receive a greater amount of rainfall then the northerly ones.

The soil is made up of loose coral sand or coral gravel, and is very porous. Surface collections of water are rare except where the level of the land is lower than the subsoil water level. Subsoil water is generally brackish, so that most of the wells have only brackish water. The Ellice Islander depends almost entirely on collected rainwater for drinking and domestic purposes. The water in young coconuts,



MAP 7. Atoll islands of the Ellice group: (1) Nukufetau, (2) Funafuti, and (3) Nukulailai



MAP 8. Reef islands of the Ellice group: (1) Nanumea, (2) Niutao, (3) Nanumanga, (4) Nui, and (5) Vaitupu

wherever available, is preferred as a drink. In olden days fresh water was obtained by arresting the flow of rain down the trunk of a coconut tree and conducting it into a large basin hollowed out of a log. Rain-water was also collected in "tree-wells" made by scooping out a large cavity in the basal part of the trunk of a living coconut tree, the rain-water streaming down the trunk being directed into this cavity by furrows cut on the trunk of the tree higher up. Ordinarily the tree-well holds very little water, rarely more than two gallons. Although these methods of collecting rain-water are still being followed, the householder of the present day collects rain-water from the tin roof of his house and stores it in barrels or drums. Many of the villages are now provided with concrete cisterns for rain-water, using roofs of churches and public buildings as catchment. These however have not eliminated the domestic container for water.

Although all the islands of the Ellices are of coral origin, two topographical types can be made out: (1) the typical atoll consisting of a broken ring of numerous narrow islets or islet-strips set on a reef surrounding a deep and spacious lagoon several miles across, and (2) the atypical atoll or, to term it more correctly, the reef island, in which the land forms a broad compact crown set on a submarine peak, and washed on all sides by the ocean. The reef island has no lagoon at all, or the lagoon is small and shallow, often reduced to a land-locked mangrove swamp. These two types of islands differ in regard to filarial incidence as will be seen later.

The three inhabited islands of the southern part of the Ellices namely Nukufetau, Funafuti and Nukulailai, are atolls (Map 7). Each of these consists of a ring of numerous islets encircling a large and deep lagoon, 6 to 13 miles in length and 2 to 10 miles in width. The islets are narrow, generally not more than two furlongs in width; many of the islets are in the form of long narrow strips several miles in length. Although the islets are covered with coconut palms and tall trees, the undergrowth on these narrow islets is not as dense as in the reef islands; some of the broader islets however have more dense vegetation and heavier undergrowth. Only one islet of the atoll is inhabited. There are no permanent settlements on any of the other islets, all of which are re-served as plantations. The village on the village islet is more compact than the villages of the reef islands.

The five islands of the northerly group of the Ellices, namely Nanumea, Niutao, Nanumanga, Nui and Vaitupu, are reef islands (Map 8).* In these, the land is broad, often a mile in all directions, and densely wooded with coconut palms, tall trees and thick undergrowth. The villages are diffuse in character, and the habitations are scattered over a wide area within the extensive plantations.

* The writer is much indebted to Group Captain A.H. Marsh for his help in providing a map of the Ellice Islands.

Non-periodic Wuchereria bancrofti infection is endemic in all the islands of the Ellice group, and the microfilaria rates are high. O'Connor (1923) carried out a very detailed investigation in the Ellice Islands. For the entire group, the over-all microfilaria rate among 1,169 persons of 16 years of age and over examined by O'Connor was 46.0 per cent. In the different islands, the microfilaria rates among persons of this age-group ranged from 28.6 to 53.9 per cent. Among 248 children aged 4 to 15 years, the microfilaria rate was 12.5 per cent. Buxton (1928) examined a smaller number of persons and only males: of 333 males over 20 years of age, 38.1 per cent harboured microfilariae in the blood; the microfilaria rates for the different islands, according to Buxton, ranged from 9.5 to 66.7 per cent. Venner (1944) examined 65 persons from Nanumea and recorded a microfilaria rate of 50.8 per cent. Lewis (1945) examined 173 persons of all ages from Nukufetau and recorded a microfilaria rate of 34.1 per cent. On Nukulailai, of 258 persons examined, 19.0 per cent were positive for microfilaria (Annual Report, Medical Department, Gilbert and Ellice Islands Colony, 1957).

Ellice Islands have a high incidence of filarial disease. Lymphangitis, hydrocele, and elephantiasis of the limbs and scrotum are extremely common. Elephantiasis often assumes gross proportions. Multiple lesions in cases of elephantiasis are of frequent occurrence. McNaughton (1919) made a census of cases of elephantiasis in the Ellice Islands, and recorded 90 cases in a total population of 3,434, an over-all elephantiasis rate of 2.6 per cent; in the different islands the elephantiasis rates varied widely, from 0.3 per cent in Nukufetau to 6.1 per cent in Vaitupu. According to O'Connor (1923), the elephantiasis rate among persons aged 16 years and over was 10.3 per cent (1,169 persons examined in the whole group). Excepting Nukufetau with an elephantiasis rate of 1.1 per cent, in the other islands the elephantiasis rates were very high, ranging between 5 and 30 per cent. Buxton (1928) examined 333 adult males and recorded an elephantiasis rate of 8.1 per cent, and a hydrocele rate of 23.0 per cent.

As was shown by O'Connor, Aedes polynesiensis is the vector of W. bancrofti in the Ellice Islands; under conditions of experimental infection, the parasite developed normally in this mosquito and reached the infective stage in 14 days. O'Connor observed that although A. polynesiensis was common on all the islands of the Ellices, its density of prevalence varied considerably, and that the incidence of filarial infection and of filarial disease in the different islands was directly related to the local exuberance of this mosquito.

Aedes polynesiensis breeds in small containers; the most important breeding sites in village areas are domestic receptacles for storing rain-water, coconut shells, tin-cans and tree-wells. As the people depend entirely on collected rain-water for their supply of fresh water, each dwelling house has a number of receptacles of various types for storing water. These receptacles form perennial breeding sites for A. polynesiensis and as they are in the immediate vicinity of the habitations they are of great importance in the epidemiology of filariasis.

Byrd and St. Amant (1959, p. 68) stated: "On the Island of Funafuti, Ellice Islands, because of the acute water shortage, several thousands of steel drums were used as water containers and hundreds of these bred mosquitoes. This type of breeding place was far in excess of all others for the Aedes mosquito on that island".

Besides the receptacles for storing water, there occurs in the backyards of houses a profusion of other breeding sites such as coconut shells and tin cans. A common drink of the Ellice Islander is the water contained in young coconuts. Shells of nuts opened for the water contained in them are commonly thrown into bush near habitations; as they contain some food matter, they form prolific breeding sites of A. polynesiensis. The enormous numbers of such breeding sites in the vicinity of habitations may be visualized from the observations of Maude (1937): "On an average an Ellice Island family requires two carrying loads of 20 nuts each daily for drinking".

The incidence of Aedes polynesiensis varies in the two types of islands of the Ellices. O'Connor (1923) observed that the prevalence of this mosquito was extremely high in the villages of the northern Ellice group, and comparatively low in the villages of the southern group. The five islands comprising the northerly group of the Ellices are broad, and the villages are diffuse in character, with dense bush and plantations all around habitations, and plentiful opportunities for the accumulation of litter capable of breeding Aedes. In these villages, Aedes polynesiensis occurs often in such numbers as to constitute a pest. In comparison with the reef islands, the village islets of the atoll islands comprising the southerly group are narrower, with less of bush around habitations, more exposed to the prevailing wind, and with comparatively fewer opportunities for Aedes to breed. This however is not invariably true for the village islets of all the three atoll islands. For instance, on the village islet of Funafuti atoll, Byrd and St. Amant (1959) found very large numbers of domestic water containers which were breeding Aedes polynesiensis; a fair amount of bush occurs in the vicinity of habitations of Fangafale village, the principal settlement. Fangawa, the village islet of Nukulailai atoll, is a relatively broad islet, three-quarters of a mile in length and more than quarter of a mile in width; this islet is densely wooded, and the scattered habitations lie within extensive plantations with dense bush all around and plentiful opportunities for Aedes breeding. Broadly speaking, it may be stated that vector density in the villages of the atoll islands is comparatively lower than in the villages of the reef islands.

Although filarial endemicity is high in all the islands of the Ellices, it reaches the hyperendemic level more commonly in the reef islands than in the atoll islands. O'Connor's findings on the incidence of filarial infection and of elephantiasis in the different islands of the Ellice group are summarized in Table 9. These data bring out the striking difference in the filarial endemicity of the two types of islands of the Ellices. In the reef islands, the microfilaria rates in persons aged 16 years and over ranged from 42.5 to 53.9, averaging 49.2 per cent;

TABLE 9

Summary of O'Connor's (1923) findings on the incidence of filarial infection and elephantiasis in the Ellice Islands, based on the examination of persons aged 16 years and over.

Island	Number exa- mined	Number positive for micro- filaria	Number with micro- filarial density over 200 in 20cmm.	Micro- filaria rate %	Number with elephan- tiasis	Number with multiple lesions	Elephan- tiasis rate %
Reef Islands (northerly group)							
Nanumea	280	151	21	53.9	24	10	8.6
Niutao	141	76	7	53.9	7	5	5.0
Nanumanga	107	53	16	49.5	15	11	14.0
Nui	126	55	8	43.7	38	19	30.2
Vaitupu	200	85	13	42.5	20	11	10.0
Total for reef islands	854	420	65	49.2	104	56	12.2
Atoll Islands (southerly group)							
Nukufetau	95	40	7	42.1	1	1	1.1
Funafuti	143	56	1	39.2	8	1	5.6
Nukulailai	77	22	1	28.6	7	0	9.1
Total for atoll islands	315	118	9	37.5	16	2	5.1

sixty-five persons (or 15.5 per cent) of the 420 positive for microfilaria showed high microfilaria counts of over 200 in 20 cmm. of blood. The elephantiasis rates of these islands ranged from 5 to 30.2, averaging 12.2 per cent; fifty-six (or 53.8 per cent) of the 104 cases of elephantiasis showed multiple lesions.

In the atoll islands, the microfilaria rates ranged from 28.6 to 42.1, averaging 37.5 per cent; nine (or 7.2 per cent) of the 118 persons positive for microfilaria showed microfilarial densities higher than 200 in 20 cmm. of blood. The elephantiasis rates ranged from 1.1 to 9.1, averaging 5.1 per cent; two (or 12.5 per cent) of the 16 cases of elephantiasis showed multiple lesions.

Although both types of islands of the Ellices have high filarial endemicity, the degree of endemicity is markedly higher in the reef islands than in the atoll islands. The incidence and intensity of filarial infection as well as the incidence and severity of cases of elephantiasis are very much higher in the former group than in the latter.

Buxton's (1928) observations (summarized in Table 10) confirm O'Connor's earlier findings. For the five reef islands of the Ellices,

TABLE 10

Incidence of filarial infection, hydrocele and elephantiasis among males over 20 years of age in the Ellice Islands, based on the observations of Buxton (1928, p. 60)

Island	Number exa- mined	Number positive for micro- filaria	Micro- filaria rate %	Number with hydro- cele	Hydro- cele rate %	Number with elephan- tiasis	Elephan- tiasis rate %
Reef Islands (northerly group)							
Nanumea	93	46	49.5	20	21.5	6	6.5
Niutao	36	24	66.7	9	25.0	2	5.6
Nanumanga	33	12	36.4	10	30.3	4	12.1
Nui	30	11	36.7	13	43.3	6	20.0
Vaitupu	54	16	29.6	13	24.1	5	9.3
Total for reef islands	246	109	44.3	65	26.4	23	9.3
Atoll Islands (southerly group)							
Nukufetau	30	7	23.3	7	23.3	1	3.3
Funafuti	36	9	25.0	6	16.7	2	5.6
Nukulailai	21	2	9.5	2	9.5	1	4.8
Total for atoll islands	87	18	20.7	15	17.2	4	4.6

the average microfilaria rate among males over 20 years of age, as determined by Buxton was 44.3 per cent, the average hydrocele rate 26.4 per cent, and the average elephantiasis rate 9.3 per cent. The corresponding rates for the three atoll islands are 20.7, 17.2 and 4.6 per cent. By each of the criteria, namely the microfilaria rate, the hydrocele rate and the elephantiasis rate, filarial endemicity is markedly higher in the northerly group of the Ellices than in the southerly group. This difference in the *filarial endemicity of the two sets of islands is due to the fact that* vector density in the villages of the reef islands is extremely high, whereas in the villages of the atoll islands, vector density is markedly lower.

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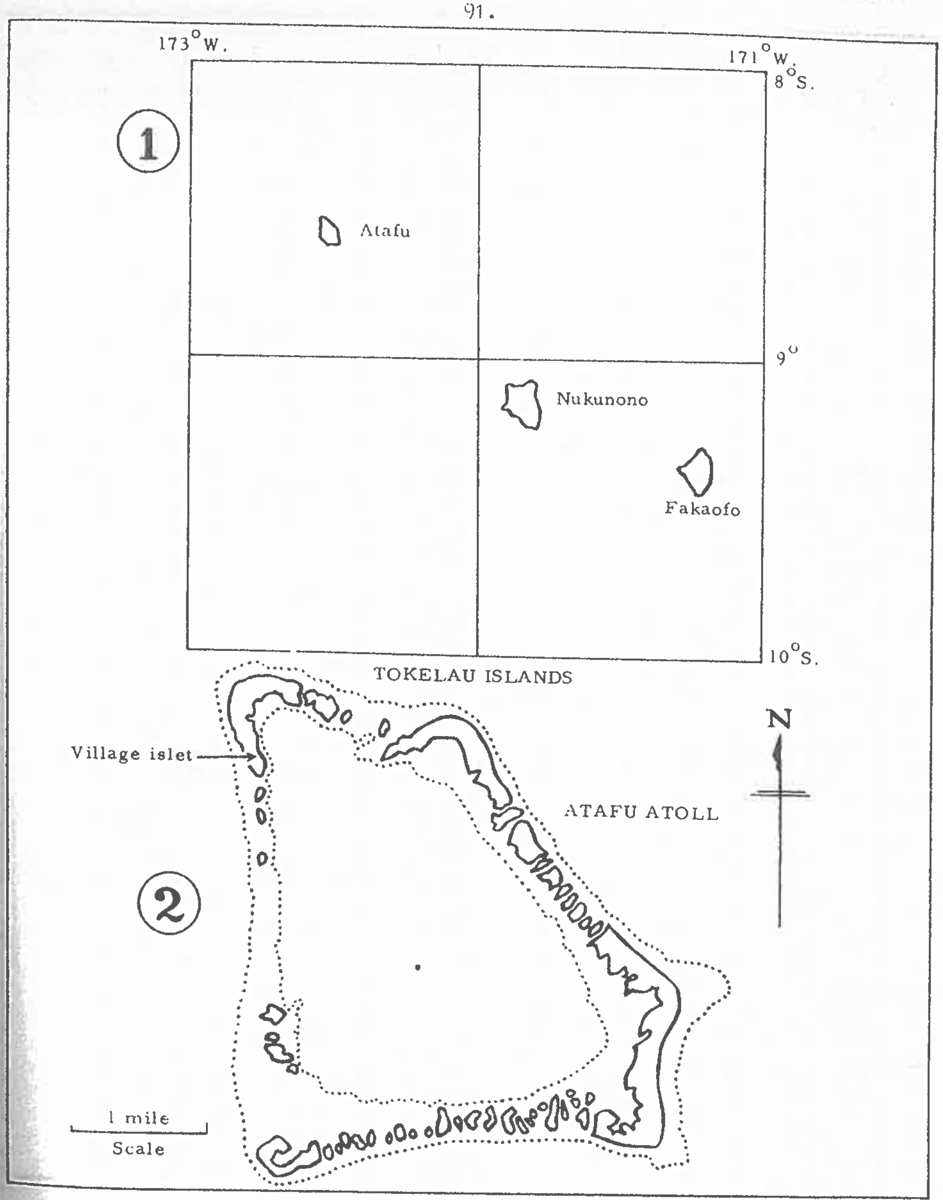
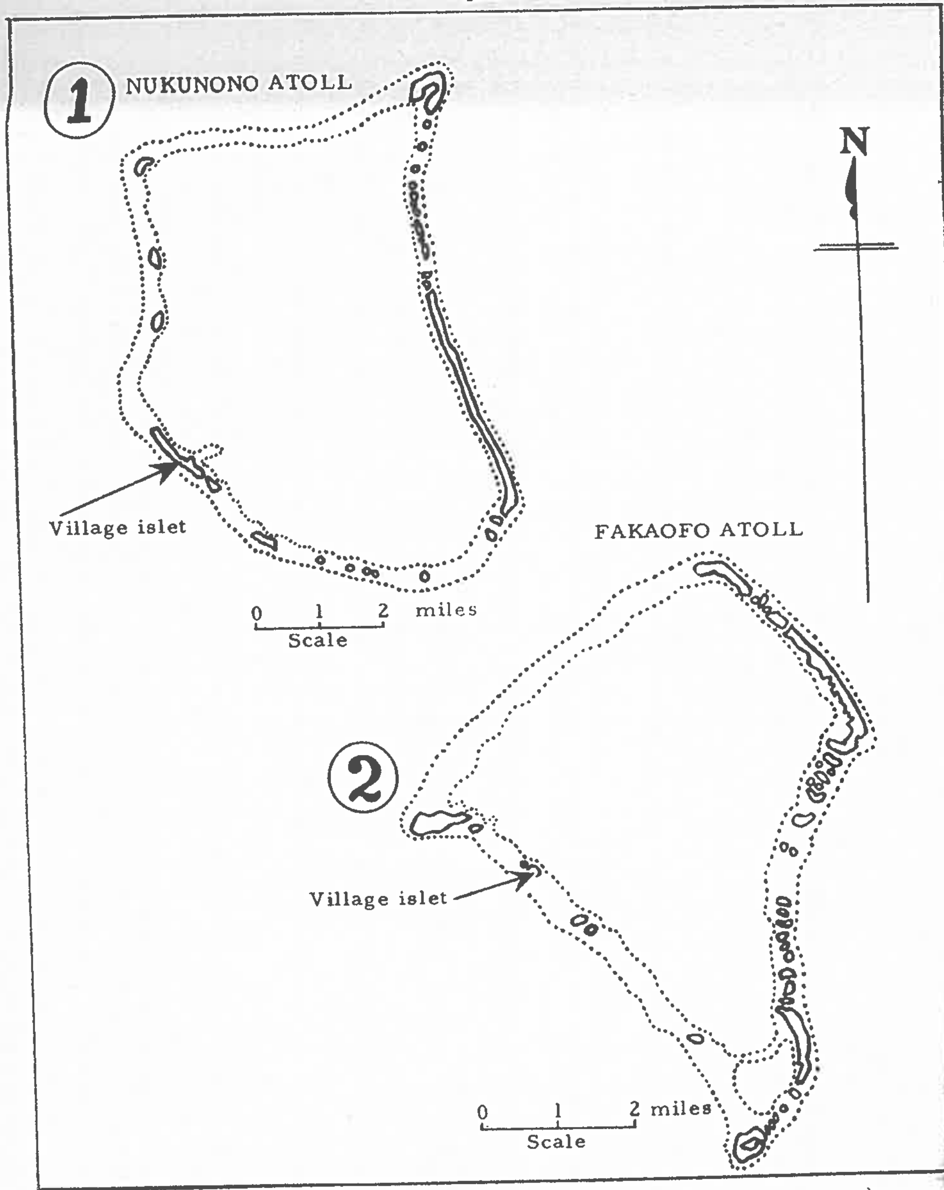
(5) Tokelau Islands

Tokelau Islands (Map 9) are situated about 300 miles to the north of Western Samoa, and lie between latitudes 8° and 10° S., and between longitudes 171° and 173° W. The group comprises three islands, each a perfect example of a coral atoll; Atafu is the most northwesterly of the group, Fakaofo is at the southeastern end, and Nukunono lies halfway between; the distance from Atafu to Fakaofo is about 180 miles. The total land area of all the three atolls together is 4 square miles.

Each of these atolls consists of a ring of surf-beaten coral reef encircling a large lagoon about 3 to 7 miles across. Every here and there the reef is raised to form narrow islets, less than 300 yards in width, and 10 to 15 feet above sea level. Atafu atoll (Map 9,2) is about 3 miles by 4, and has 19 islets with a total land area of 550 acres; Nukunono (Map 10,1) is 7 miles by 5, and has 30 islets with a land area of about 2 square miles; Fakaofo atoll (Map 10,2) is 7 miles by 5½, and has 61 islets with a land area of about one square mile. Although there are many islets in each of these atolls, only one islet of the atoll is inhabited. The total population of the Tokelau group is about 1,600, distributed as follows: Atafu 490, Fakaofo 670, and Nukunono 460.



MAP 9. Tokelau Islands (1) and Atafu atoll (2)



MAP 10. Nukunono (1) and Fakaofo (2) atolls (Tokelau Islands)

During the early part of the 19th century each of the three atolls had a number of villages located on the larger islets of the atoll. Between 1850 and 1870, Peruvian slavers made several raids on the villages of Tokelau and carried off many hundreds of Tokelau natives as slaves for labour on South American plantations. Subsequent to the depredations by the slavers, the population of each atoll, chiefly as a measure of collective security, had confined itself to a single islet on the leeward (westerly) side of the lagoon. Even at the present day, the same practice is being followed: the entire population of each atoll lives on a single islet, called the "village islet". The other islets of the atoll are set apart as coconut plantations and timber reserves, and for growing food crops. Although the plantation islets are visited from time to time for collecting coconuts and other produce, there are no permanent habitations on any of them, and no one is allowed to reside there. There is some congestion of population on the village islet of Fakaofo atoll which is only about 12 acres in extent and accommodates 660 people. The village islets of the atolls Atafu and Nukunono are larger in size, and the populations are smaller (460 to 490): these islets are not as crowded as the village islet of Fakaofo. "At Fakaofo where overcrowding has been a problem for several years, a resettlement scheme has recently been undertaken, and at the end of the year under review some 40 families had already established themselves on the neighbouring islet of Faruafale" (Official Report for the year 1957-58). It is understood that a similar resettlement scheme is envisaged for Nukunono.

Rainfall in Tokelau ranges between 100 and 140 inches annually, and is well distributed over the year; there is no marked dry season. From the end of November to the end of February, rainfall is comparatively less. Temperature shows little change and averages 82° F. In the different months the mean daily maximum temperature ranges between 86° and 88° F., and the mean daily minimum between 76° and 78° F. Atmospheric humidity is high.

There is little surface water on the islands: the soil, which consists of pounded coral, is porous. There are a few wells on the village islets, but the water in them is brackish. Collected rain-water is the only source of fresh water. Rain-water is however only occasionally used for drinking; the common drink of the Tokelau Islander is the water in tender coconuts. Before modern storage facilities were available, the natives conserved rain-water in tree-wells, or "tungu" as they are locally called. A tree-well is made by scooping out a large cavity in the basal part of the trunk of a living coconut tree; the tree itself acts as catchment, and channels cut on the trunk of the palm above the scooped-out cavity serve to direct the rain-water streaming down the trunk into the tree-well. At the present time, very few tree-wells exist on the village islets, although there are many of the plantation islets. During the past 30 years or so, large modern concrete cisterns (5000 to 12000 gallon capacity) have been erected on each of the village islets for storing rain-water, using the roofs of churches and public buildings as catchment, in addition to a number of smaller tanks.

The village islet is kept clean and tidy. "The islanders take a great pride in the appearance of their homes, which, together with the village paths and grounds, are kept in immaculate order" (Official Report for 1953). Little breeding of _Aedes polynesiensis_ occurs on the village islet. There is practically no bush, and very little of litter. No uncultivated land is left for superfluous bush. Owing to limitations of space, all rubbish is thrown into the lagoon. Very little opportunity is offered for the breeding of _Aedes_ in the village areas. Laird (1955, p. 296) says: "No coconut shells holding water and suitable as breeding places (for _Aedes_) could be found on Nukunono, a tribute to the state of cleanliness in which the village and its surroundings are maintained". Similar conditions prevail in the villages of the other two atolls as well. As there are large communal cisterns for rain-water on each of the three village islets, the people do not have to keep containers for for storing water which may afford facilities for _Aedes_ breeding. The household water-receptacles are replenished twice or thrice a week from the large communal cistern of the village, and these receptacles are often completely emptied out before refilling (Laird 1960). Adult _Aedes polynesiensis_ mosquitoes are only rarely seen in the villages of Tokelau.

On the plantation islets, on the other hand, conditions are highly favourable for the breeding of _A. polynesiensis_, and a high density of adult mosquitoes prevails. A profusion of breeding sites favourable for this mosquito exists on the plantation islets, such as tree-wells, tree-holes, and rat-damaged coconuts. Of these, the most prolific breeding site for _Aedes_ is the rat-damaged coconut.

A species of rat, _Rattus exulans_, infests the coconut plantations in Tokelau. This rat, which nests on the palms, attacks the young coconuts while still on the trees. It gnaws a circular hole at the base of the half- to three-quarter-ripe nut to get at the contents. The damaged coconut subsequently falls to the ground, and after a few weeks it forms a prolific breeding site for _A. polynesiensis_. The heavy rainfall keeps these rat-opened coconuts filled with water, and the dense undergrowth in the plantations provides shelter from sun and from wind for the breeding sites and for the adult mosquitoes that have emerged. The ground in the coconut plantations is heavily littered with rat-damaged coconuts, their number being often beyond computation. As the plantation islets are closely planted with coconut palms, and as 40 to 60 per cent of the coconut crop, according to official estimates, is destroyed by the rat, the number of rat-damaged coconuts in the plantations must be something enormous. Ideal conditions prevail in the plantation islets for a very high density of _A. polynesiensis_, namely the large numbers of favourable breeding sites, the heavy rainfall, and the dense undergrowth serving to protect the breeding sites and the adult mosquitoes from sun and wind.

There is thus a marked contrast between the village islets where the people live, and the plantation islets visited by them for collecting produce, in regard to the prevalence of _Aedes polynesiensis_. In the former, this mosquito is practically absent, whereas in the latter it occurs in very large numbers.

Although no one lives permanently on the plantation islets, they are visited by the people at periodic intervals. The Tokelau Islanders follow a system of controlled communal farming. For purposes of tending their plantations and for collecting the produce, the people are permitted to go to the plantation islets only during periods notified by the Atoll Council from time to time, and they have to return to the village within a specified period. This practice has an important bearing on the epidemiology of filariasis in Tokelau as will be seen later. MacGregor (1937, p. 58) says: "Plantation lands are still set aside in rotation for the production of copra. Formerly the Council of Fakaofo and the High Priest placed a tapu on visiting all plantations of the atoll. Every few days the tapu was removed and all the people visited their plantations at the same time to gather food. This custom prevented the theft of coconuts and pandanus and kept a check on the food supply". The same procedure is still being followed. The plantation islets are not visited except during periods specified by the Council of Elders of the atoll.

Non-periodic _W. bancrofti_ infection is endemic in Tokelau (O'Connor 1923, Buxton 1928). The incidence of the infection in the population is fairly high. Of 320 persons (all ages) examined by O'Connor, 18.8 per cent were positive for microfilaria in the blood. The microfilaria rate among persons aged 16 years and over was 22.4 per cent for the group (range 18.5 to 23.3 per cent for the three atolls). Buxton examined a smaller number of persons, and only males, from the two atolls, Atafu and Fakaofo; the microfilaria rates in males over 20 years of age of the two atolls were 23.3 and 21.3 per cent respectively. Laird (1955) examined 97 persons (all ages) from Nukunono and found 17.5 per cent positive for microfilaria. During 1958, Laird and Colless (1959) examined 324 persons (all ages) from Tokelau and found 18.5 per cent positive for microfilaria; the microfilaria rates for the three atolls were: Nukunono 14.1 per cent, Fakaofo 19.2 per cent, and Atafu 21.9 per cent.

Filarial infection in Tokelau is of a low grade as judged by the microfilarial density in the blood of the carriers. The highest microfilaria count (in 20 cmm. of blood) recorded by O'Connor in Fakaofo was 87, and in Nukunono 33. The highest count noted by Laird (1955) in Nukunono was 30. The vast majority of the infections seen by Laird and Colless (1959) in the Tokelau Islands were of a very low grade; of the 60 positives recorded by these observers, 22 showed microfilaria counts of less than 10 per 20 cmm.; in 22 cases the counts were between 10 and 24, in 10 cases between 25 and 49, and in 6 cases over 49.

A noteworthy feature is that cases of filarial disease are rare, even though 18 per cent of the population of Tokelau show demonstrable microfilaraemia. O'Connor (1923) who made a detailed study of one-third of the total population of Tokelau during 1920, failed to find even a single case of elephantiasis. He stated that "no cases of elephantiasis were seen, and none had been reported for many years". During 1924, four years after O'Connor's investigations in Tokelau, Buxton made a brief visit to Tokelau and recorded 5 cases of elephantiasis out of 47 males examined from Atafu, and none out of 43 from Fakaofo; he also noted 10 and 5 cases of hydrocele in Atafu and Fakaofo respectively. MacKay (1928) stated that he found 15 cases of elephantiasis in Tokelau and a few cases of hydrocele; nevertheless, he stated that elephantoid fever was rare in Tokelau. The finding of cases of elephantiasis in Tokelau by Buxton and by Mackay within a few years after the negative finding by O'Connor seems difficult to explain unless it be that the cases seen by them were imported cases. However, none of the later reports on Tokelau mentions of the occurrence of cases of elephantiasis there. Laird and Colless (1959) state: "No cases of elephantiasis were seen and very few people had even slight filarial swellings". It is now generally recognized that cases of filarial disease are of rare occurrence in Tokelau.

Although no studies have been made to determine the vector of W. bancrofti in Tokelau, there can be little doubt that Aedes polynesiensis is the vector. The facts that W. bancrofti is endemic in Tokelau and that A. polynesiensis is the only mosquito occurring there would justify this assumption.*

Filarial disease is not a problem in the Tokelau Islands even though an appreciably high incidence of endemic filarial infection is present. The virtual absence of filarial disease in Tokelau is due to the fact that local conditions and the habits of the people are not favourable for the establishment of hyperfilariation in the human host. The low grade character of the infection noted in microfilaria carriers in Tokelau supports the view that facilities for intensive transmission are extremely poor.

The people of Tokelau do not live in close contact with high density of the vector mosquito in any one locality all the time, or even for any appreciable length of time, such as to facilitate intensive transmission and repeated re-infection. On the village islets where the people live, the vector mosquito is virtually absent and consequently no transmission is possible. On the plantation islets which are visited by the islanders, vector density is very high. As was mentioned earlier, the time for visits to the plantation islets is determined by the Village Council. From time to time certain plantation areas are declared open for specified periods for purposes of collection of produce. On these trips, able-bodied men accompanied by a few women go to the plantations, leaving behind in the village islet the majority of the women and children and the old menfolk. The collecting parties go to their respective plantation areas, camp in selected spots, and collect copra and other produce. When an area has been harvested the party shifts its camp to another site in the plantation or returns to the village islet with the produce, keeping strictly to the time schedule set out by the Atoll Council.

*Another species, Aedes (Aedimorphus) vexans nocturnus, has recently been found in a small focus on Fanuafala islet of Fakaofo atoll (Laird & Colless 1959).

While working and camping in the plantations, which as stated earlier are heavily infested with A. polynesiensis, the members of the collecting party are exposed to bites by large numbers of this mosquito. A proportion of the vector population of that particular area would get infected with W. bancrofti derived from microfilaria carriers among the collecting party. Ordinarily each of these parties completes the harvesting of the alloted area in one to two weeks and then moves on to a new site. As the shifting of the camp frequently happens within the period of incubation of the parasite in the mosquito host, and before the infection in the mosquito has reached the infective stage, no transmission is likely to occur. At the new site where they camp and work, the people would be exposed to bites by mosquitoes which are free from the infection. When they return to the village islet where the vector mosquito is only rarely to be seen, they are not exposed to any chances of infection. As the different plantation areas are worked in rotation, and as the same locality is not likely to be visited again for several months thereafter, any filarial infection acquired by the mosquitoes present in any particular area in the plantation from a collecting party that had worked there previously, would have died out by the time that area is visited again for produce collection.

Whenever it happens that a collecting party stays at the same camp site on a plantation for a longer period, long enough for the parasite in the infected mosquito to develop to the infective stage, transmission of the infection is possible. That this happens not infrequently, and that transmission of filarial infection does occur in the plantation areas under such circumstances, is evidenced by the maintenance of endemic filarial infection in a significant proportion of the population. But because of the necessity to complete the harvesting of an area within the allotted time and then to return to the village islet, the people do not stay in the same part of the plantation and in contact with the same vector population long enough to facilitate continuous and intensive transmission necessary for hyperfilariation. The customs and habits of the Tokelau Islanders thus furnish an explanation for the absence of cases of filarial disease among them.

The incidence of filarial infection in the different sections of the population of Tokelau bears a direct relation to exposure to infection on the plantation islets. There is a marked difference between the microfilaria rate observed among those who spend most of their time on the village islet, and that among those who frequently visit the plantations. Children and adolescents stay mostly in the villages and only infrequently go to the plantations; among them, filarial infection is totally absent or the infection rate is very low. The data presented in Table 11 bring out the difference in the infection rates among children and adults of Tokelau.

A marked difference has also been noted in the microfilaria rates of adult males and adult females. It was mentioned that only a small proportion of the women go to the plantations with the collecting parties. Consequently the adult female population is exposed to infection to a much

TABLE 11

Incidence of filarial infection in children and adults in Tokelau

Age-group	Number examined	Microfilaria rate	Authority
5 to 10 years	85	8.2	O'Connor (1923)
16 years & over	245	22.4	" "
Males under 20	17	5.9	Buxton (1928)
Males over 20	90	22.2	" "
1 to 19 years	31	0	Laird (1955)
20 years & over	66	25.8	" "
1 to 9 years	31	0	Laird & Colless
10 to 19 years	67	4.5	" (1959)
20 years & over	226	25.2	" "

smaller extent than the adult males. Among persons of 16 years of age and over, O'Connor (1923) determined the microfilaria rates for males and females as 31.2 and 13.3 per cent respectively. According to Laird (1955), the microfilaria rates for adult males and females (20 years and over) in Nukunono were 42.7 and 13.2 per cent respectively. The observations of Laird and Colless (1959) in the three atolls of Tokelau also bring out the same feature (Table 12).

TABLE 12

Microfilaria rates in males and females aged 20 years and over from the three atolls of Tokelau (after Laird & Colless 1959).

Atoll	Males		Females	
	Number examined	Microfilaria rate	Number examined	Microfilaria rate
Nukunono	32	28.1	40	12.5
Fakaofo	32	46.9	42	14.3
Atafu	36	38.9	44	18.2

The observations cited above show that the incidence of filarial infection in the population of Tokelau is in direct relation to the extent of exposure to infection on the plantation islets, there being little opportunity for acquiring the infection on the village islet, which is practically free from the vector mosquito.

In spite of the occurrence of endemic filarial infection, and even of very high microfilaria rates (28 to 47 per cent) in the adult male population of Tokelau, cases of elephantiasis are totally absent. Even filarial lymphangitis is rare (O'Connor 1923). This is due to the fact that local conditions and the habits of the people are not favourable for continued re-infection and hyperfilariation, even though transmission of filarial infection does occur. O'Connor showed that in Tokelau there was lack of intimate and persistent contact of the population with the mosquito vector. The people do not live in close and constant contact with high vector density. On the village islets, the vector mosquito is practically absent. On the plantation islets where vector density is high, the people do not stay in any one locality and in contact with the same vector population for any appreciable length of time to facilitate intensive transmission and repeated re-infection.

If, however, there should be a change in the way of life of these people, and if they happen to settle permanently on any of the plantation islets heavily infested with the vector mosquito, conditions would be highly favourable for intensive transmission and, as a result, filarial disease would manifest itself among them. It mentioned that some schemes are under contemplation for settling part of the populations of certain congested villages on plantation islets at present uninhabited. Such schemes are fraught with the risk of filarial disease, unless effective measures are undertaken to control vector breeding in the areas proposed to be colonized.

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(6) Wallis and Hoorn Islands

Wallis and Hoorn Islands are two small groups of high islands of volcanic origin, about 120 miles apart, and situated between latitudes 14° and 16° S., and between longitudes 178° and 176° W. The Wallis group consists of the main island of Uvea, commonly known as Wallis Island, with an area of 24 square miles, and a number of tiny uninhabited islets on or within an encircling coral reef. An extensive central plateau, 200 to 400 feet in elevation, forms the greater part of Uvea which is skirted nearly all round by a narrow, flat coastal strip, only a few hundred yards in maximum width; its total population is 6,500. The people live in an almost continuous village on the coastal strip along the east and south coast of the island. The Hoorn Islands comprise two small mountainous islands, Futuna and Alofi, rising to elevations of 2600 and 1300 feet respectively, and separated by a deep narrow strait. The total area of the Hoorn Islands is 34 square miles, and the total population 2,800.

Climate is tropical-oceanic. Atmospheric humidity and temperature are high throughout the year. Diurnal range of temperature is small, about 6° to 10° F. Rainfall is heavy, over 100 inches annually.

Much of the information that we have on filariasis refers to Wallis Island; very little is known about conditions prevailing in the Hoorn group. Filarial disease has long been known to be very prevalent on Wallis Island. Reynaud (1876), Clavel (1884) and Saffre (1884) reported that cases of elephantiasis were very common among the Wallisians. Reynaud stated that even white people were often affected with the disease. Clavel observed that the affected part may attain an enormous size; in a case of crural elephantiasis, the circumference of the middle part of the leg was as much as 120 cm. Viala (1909) stated that nearly 50 per cent of the population of Wallis Island suffered from elephantiasis, chiefly of the leg and scrotum; he also noted that hydrocele was very common among adult males. Brochard (1910b) stated that 20 per cent of the population of Wallis Island were affected with elephantiasis. David (1939) reported that elephantiasis was extremely common in the Wallis Islands, and that 45 per cent of the population of Uvea had elephantiasis, mostly of the leg and scrotum; multiple lesions in cases of elephantiasis were common, and simultaneous affection of all four limbs and the scrotum was by no means rare. David stated that it was not unusual to find young people, and even a few eight- and ten-year old children with enormous elephantoid legs. Rageau and Estienne (1959) reported that 10 per cent of the population of Wallis Island had clinical filariasis (lymphangitis-elephantiasis).

In regard to the islands of the Hoorn group, we do not have much information. Viala (1909) stated that elephantiasis was extremely common in Futuna, but the incidence was slightly lower than in Wallis Island. David (1939) stated that elephantiasis was very common in Futuna.

As was first shown by Brochard (1910a), the causative organism in Wallis Island is the non-periodic W. bancrofti. Byrd and St. Amant (1945) observed that the microfilaria occurred in the peripheral blood in nearly

equal numbers during daytime and at night; microfilarial density appeared to reach a maximum between the hours 1600 and 2000, which in the opinion of these workers did not constitute true periodicity. Rageau and Estienne (1959) also demonstrated the absence of periodicity of the microfilaria in Wallis Island; although microfilariae were found in more or less equal numbers at all hours of the day and night in the three cases studied by them, some fluctuation was noted suggestive of a peak microfilarial density at 1600 hour, and comparatively low densities between the hours 2400 and 0600 (Table 13).

TABLE 13

Average microfilaria counts in 20 cmm. of peripheral blood in three carriers from Wallis Island studied by Rageau and Estienne (1959)

Hour	Average microfilaria count
0800	225
1000	216
1200	232
1400	253
1600	363
1800	298
2000	250
2200	273
2400	189
0200	248
0400	166
0600	140

Touze (1954) stated that 40 per cent of the natives of Wallis Island harboured microfilaria in the blood. Rageau and Estienne (1959) from an examination of 1029 persons (all ages) recorded a microfilaria rate of 20.4 per cent; in the different villages, the rates varied between 5.5 and 36.3 per cent. The incidence of the infection was about equal in the two sexes, males 21.8 per cent, females 19.2 per cent. The microfilaria rates showed an increase with age, reaching a peak in the age-group 41-50 years, after which it declined slightly; the incidence of clinical filariasis showed a progressive increase with age (Table 14).

The vector of W. bancrofti in Wallis Island is Aedes polynesiensis. Of 770 specimens of A. polynesiensis examined from different villages on Wallis Island, Byrd and St. Amant (1959) found 12.2 per cent naturally infected with larval stages of W. bancrofti. In the infected specimens, all stages of development of the filaria larva were seen, including the full-grown infective stage. Within the native village

TABLE 14

Incidence of filarial infection and of clinical *filariasis* (*lymphangitis-elephantiasis*) in different age-groups in Wallis Island (after Rageau & Estienne 1959)

Age-group	Number examined	Microfilaria rate	Clinical filariasis rate (lymphangitis-elephantiasis)
0-9	15	13.3	0
10-14	59	8.4	1.6
15-19	152	14.4	1.9
20-30	261	20.6	3.4
31-40	239	19.2	11.7
41-50	188	28.7	18.0
51-60	87	22.9	24.1
over 60	28	25.0	21.4

the infection rate in the vector mosquito ranged between 6 and 23 per cent, rising as high as 38 per cent in certain sections of the villages. Outside of the native habitations, the infection rate in the vector was extremely low. Byrd and St. Amant showed that the infection rate in the vector was related to the extent of its contact with the native population. Rageau and Estienne (1959) recorded a natural infection rate of 3.7 per cent in A. polynesiensis (1,435 specimens examined from different parts of Wallis Island).

The density of adult A. polynesiensis in the inhabited areas is very high due to the presence of innumerable breeding places. Barrels and drums for storing rain-water are important and perennial breeding sites for this mosquito in the vicinity of habitations. The people depend on collected rain-water for their supplies of fresh water, and every house has several containers for storing water. In bush near habitations there occur large numbers of small temporary breeding sites like coconut shells and tin-cans. Of these, the most prolific source of Aedes breeding is the rat-damaged coconut. Rats cause considerable damage to the coconut crop on Wallis Island. The coastal strip where all the habitations are located is extensively planted with coconut trees, and the ground is littered with large numbers of rat-damaged coconuts. Rainfall being heavy, these small breeding sites are kept constantly filled with water, thus favouring continuous breeding of the vector mosquito all through the year. The profusion of breeding sites in the vicinity of habitations accounts for the high vector density in the villages of Wallis Island.

In the Hoorn Islands, two species of the Aedes scutellaris group, namely A. polynesiensis and A. futunae, are known to be present. These two closely allied species are similar in their feeding and breeding habits. Although definite information is lacking, it seems probable that both species are important vectors of W. bancrofti in the Hoorn Islands where filarial endemicity is known to be very high.

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(7) Western Samoa

Western Samoa lies between latitudes 13° and 14° S., and between longitudes 171° and 173° W. It comprises two large mountainous islands of volcanic origin, Savaii (700 square miles) and Upolu (430 square miles), and two tiny islands Manono and Apolima. Both Savaii and Upolu are covered with dense tropical vegetation, except for an extensive area in the northern and central part of Savaii which was covered with lava and volcanic detritus during the volcanic eruptions that occurred during 1905 and 1911.

The climate of Western Samoa is tropical-oceanic. Temperature is relatively constant. Average temperature is 85° F. Mean relative humidity is high and ranges between 80 and 85 per cent. Rainfall is heavy, averaging 112 inches annually for the northern coastal areas, and about 160 inches for the south coast. Rainfall is well distributed over the year; it is somewhat heavier during November to April than during June to September.

The total population of Western Samoa is about 100,500. Although Savaii is much the larger of the two islands, its population is only a third of the population of Upolu. On both islands, the villages are mostly situated on the narrow coastal strip, the hilly and undulating areas in the interior being practically uninhabited. There are a few small villages in the interior, besides labour settlements in the plantations, some of which extend several miles inland. The largest concentration of population, besides the township of Apia, is in the villages along the north coast of Upolu Island.

The Samoan village is of the diffuse type, with houses well apart from one another. The front side of the village is kept tidy and free from litter and rank vegetation, whereas the back side is often unkempt and overgrown with bush; in many villages there is a stone wall behind the row of houses, and the area beyond this wall is used as pig-sties and as dumping ground for litter.

Formerly the villagers depended mainly on collected rain-water for their supplies of fresh water. In villages with a foot-hill spring within easy reach, the people brought the spring water and stored it in domestic containers. During the past 45 years, increasing numbers of villages have been provided with piped water supply, tapping springs at the foot-hills. In many others, large communal cisterns have been erected for rain-water collected from roofs of large buildings and churches. In the villages provided with such water supply, domestic containers for storing rain-water are no longer in use.

Western Samoa has been notorious for its high incidence of filarial disease since early times. In the Archives de Médecine Navale of 1866, it was mentioned that the incidence of elephantiasis was very high in Western Samoa and that hydroceles were extremely common. Königer (1878) noted the high frequency of occurrence of elephantiasis among Samoans. The incidence of elephantiasis of the limbs was stated to be about equal in the two sexes. Among males, elephantiasis of the scrotum was found to be extraordinarily frequent, and the scrotal tumours often attained an enormous size. Königer observed that in some families all the members excepting young children were affected with elephantiasis, and that in a few cases even young persons, less than 20 years of age, had the disease. Turner (1890) stated that "in Samoa elephantiasis arabum prevails to a fearful extent"; he saw several scrotal tumours of an enormous size. Many other observers of that period had reported on the extremely high prevalence of elephantiasis in Samoa, as for example Hirsch (1886), Manson (1894 & 1896), Wise (1893) and Kraemer (1903). Leber (1914) reported that 60 per cent of the adult population of Western Samoa were affected with elephantoid swellings or suffered from filarial inflammations.

More recent observations on the incidence of elephantiasis in Western Samoa are the following. O'Connor (1923) examined 4,294 persons (all ages) from Eastern and Western Samoa, and recorded 115 cases of elephantiasis (2.7 per cent); over 50 per cent of these cases showed more than a single lesion. Buxton (1928) examined 1,103 males (all ages) from Western Samoa and recorded an elephantiasis rate of 5.6 per cent; the rate for adult males (20 years and over) was 9.8 per cent. As many as 35 of the 80 cases of elephantiasis seen by Buxton showed more than a single lesion. The incidence of the disease was noted to be much higher in Savaii (6.4 per cent) than in Upolu (3.5 per cent). Iyengar (1954) recorded an elephantiasis rate of 3.6 per cent for Upolu and Savaii combined. For Laulii village on Upolu, McCarthy and Fitzgerald (1955) recorded an elephantiasis rate of 2 per cent. Buxton (1928) observed that the incidence of elephantiasis among males showed a progressive rise with age; under 21 years, nil; 21 to 35 years, 1.8 per cent; 26 to 35 years, 4.8 per cent; 36 to 45 years, 12.8 per cent; over 45 years, 20.3 per cent.

Other manifestations of filarial disease like lymphadenitis and lymphangitis are extremely common. From 15 to 25 per cent of the population are subject to periodical attacks of lymphangitis (Iyengar 1954). Hydrocele is very common in Western Samoa. Buxton observed that 16 per cent of 1,103 males (all ages) had hydrocele. The hydrocele rate was higher in Savaii (17.1 per cent) than in Upolu (13.5 per cent). The incidence of hydrocele, according to Buxton, showed a progressive increase with age; under 16 years, nil; 16 to 20 years, 4.7 per cent; 21 to 25 years, 14.5 per cent; 26 to 35 years, 23.6 per cent; over 35 years, 31.7 per cent.

The recorded microfilaria rates for Western Samoa range from 17 to 41 per cent; 28.7 per cent for Eastern and Western Samoa combined (O'Connor 1923); 23.7 and 41.0 per cent for Upolu and Savaii respectively (Buxton 1928); 19.2 per cent for Upolu and 24.1 per cent for Savaii (Iyengar 1954); 17.1 per cent for Laulii village on Upolu, and 33 per cent for Tuasivi on Savaii (McCarthy & Fitzgerald 1956). O'Connor found several children aged 5 years positive for microfilariae in blood. Lopdell (1953) recorded a microfilaria rate of 14.8 per cent in school children aged 11 to 20 years. Microfilaria rates in different age-groups based on Buxton's observations are as follows: under 6 years, nil; 6 to 10 years, 3.8 per cent; 11 to 15 years, 16.9 per cent; 16 to 20 years, 31.6 per cent; 21 to 25 years, 40 per cent; 26 to 35 years, 49.5 per cent; 36 to 45 years, 44.9 per cent; over 45 years, 47.7 per cent.

O'Connor incriminated Aedes polynesiensis as the vector of non-periodic W. bancrofti in Western Samoa; of 100 specimens caught in a bungalow, 7 were found infected with W. bancrofti; under conditions of experimental infection, the parasite completed its development to the infective stage in 13 days. More recent data on natural infection rates in A. polynesiensis from Western Samoa are 7.4 per cent (Philipps 1954) and 11.1 per cent (Iyengar 1954).

The important breeding sites of A. polynesiensis are small containers like coconut shells, rat-damaged coconuts, tin-cans and domestic receptacles for storing water. Rats cause heavy damage to coconuts in Western Samoa, and it is very common to find the ground in coconut plantations heavily littered with rat-damaged coconuts. A profusion of such breeding sites occurs in the peripheral areas of most of the villages in Western Samoa.

In villages provided with either piped water supply or with large communal cisterns for storing rain-water, the domestic container for rain-water has been practically eliminated, and is not an important source of Aedes breeding. In villages without piped water supply or communal rain-water cisterns, such containers exist, often in large numbers and serve as prolific breeding sites of A. polynesiensis. Apart from these, there are numerous small breeding sites in the village areas. Lopdell (1953) reported the finding of innumerable coconut shells and tin-cans close to habitations; he stated that there were seldom less than 300 to 400 of these within 50 yards of the average Samoan house. The intensity of Aedes breeding in coconut shells was often very high; Lopdell found over 100 second and third instar larvae of A. polynesiensis, and many more younger larvae in a single coconut shell. O'Connor stated that shade and still atmosphere are the conditions highly favourable for A. polynesiensis and that "in Samoa, these conditions exist in and around every village". The occurrence of rainfall during all months of the year favours continuous breeding of Aedes in these breeding sites. The high temperature and high humidity prevailing all through the year are congenial for perennial transmission of filarial infection. The extent of transmission would probably be very much greater during November to April than during other months of the year; rainfall being heavy during this period, the breeding incidence of the vector reaches a high level.

Lopdell (1953) considers that transmission of filarial infection occurs primarily in the villages and only to a small extent in the plantation areas. Iyengar (1954) observed that infected specimens of A. polynesiensis were found mostly within the Samoan village or at its periphery, and only very rarely in areas away from habitations. Examination of mosquitoes caught in bush areas and plantations gave consistently negative results, even though such areas were occasionally visited by the village-

folk. Infected mosquitoes encountered during surveys of plantation areas were all from localities close to houses occupied by labourers. Iyengar (1954) stated: "In the immediate vicinity of villages (of Western Samoa), a high incidence of adult Aedes polynesiensis was observed and a high natural infection rate was recorded. In bush and plantations well removed from habitations the incidence of adult A. polynesiensis was variable, and quite frequently low in comparison with that observed at the outskirts of the villages; the natural infection rate in the mosquito vector as well as the average number of filaria larvae in the infected mosquitoes were much lower in plantation areas than in the vicinity of villages. Although transmission of filarial infection does occur in the vicinity of habitations as well as in bush and plantations, by far the largest extent of transmission occurs in and around the villages. In the latter situation the vector mosquito has close contact with man, thereby obtaining maximum opportunities for getting infected from microfilaria carriers and subsequently for transmitting the infection to man. In bush and plantations the Aedes polynesiensis populations, because of their limited range of flight, are localized, and the facilities for obtaining infective feeds as also for subsequently transmitting the infection to man are markedly less owing to lack of constant contact with the human host. The areas of primary importance as regards transmission of filarial infection are those in and around the villages".

McCarthy and Fitzgerald (1956), on the other hand, believe that "infection and re-infection of the human host occurs primarily in the plantation areas and along bush paths".

There has been, during the past forty years, a marked regression in filarial incidence and in the severity of manifestations of filarial disease in Western Samoa. The gross manifestations noted by earlier workers are extremely rare at the present time. Both O'Connor (1923) and Buxton (1928) reported that a high proportion of the cases of elephantiasis seen by them showed multiple lesions; at the present time, multiple lesions are infrequent. McCarthy and Fitzgerald (1955) from a comparison of their 1953 findings in Western Samoa with those of O'Connor during 1920 and of Buxton during 1925, stated that "there has been an appreciable reduction in filarial incidence during the past 30 years". These authors say: "The reason for this is not known with certainty but it does not appear to have resulted from planned control measures or from educational propaganda. It is, however, now suggested that, with the passage of time the village areas have been slowly cleared through domestic demands for firewood and other purposes. The villages therefore are now more open than formerly and in consequence less attractive to A. polynesiensis which has retreated with the bush, leaving the villages relatively free as a focus of infection". This, and probably also the increased use of clothing by the people are mentioned by these authors as the probable reasons for the reduction noted in filarial incidence.

The present writer considers that the main factor responsible for the regression in the incidence and severity of filarial disease in Western Samoa is the improvement effected during recent times in the environmental sanitation of the villages. Besides the increase in population density and improved housing, a marked change has been brought about as a result of the provision of piped water supply for a large number of villages, and the erection of communal cisterns for rain-water in many others. Prior to 1918, none of the inhabited areas of Western Samoa had piped water supply. Since then, an increasing number of villages have been provided with piped water supply, tapping springs at the foot-hills. During 1920-1921, 11 villages on Upolu Island, besides a part of the township of Apia had been provided with piped water supply. The piped water supply scheme for Apia town was completed in 1924, and by 1929, 22 villages on Upolu and 7 villages on Savaii had the benefit of piped water supply. Very considerable progress has since been made with this project, and nearly all villages with sources of fresh water available close at hand are now served with piped water supply. For many of the villages which do not have a fresh water spring within easy reach of the village, large communal cisterns for rain-water have been constructed, using roofs of church buildings as catchment. The progress made in this connection has been greater in the more populous island of Upolu than on Savaii. Nevertheless, a very considerable proportion of the population of Western Samoa, estimated at about 70 per cent of the total population, now have the benefit of either piped water supply or concrete storage tanks for rain-water.

The provision of alternative sources of fresh water has eliminated to a very large extent the domestic receptacles for storing rain-water that had existed previously. Domestic water containers play a very important role in the maintenance of high filarial endemicity. The close proximity to habitations of these perennial and prolific breeding sites of the vector mosquito ensures continuous vector breeding, high vector density inside houses and their surroundings, and maximum opportunities for intensive transmission and repeated re-infection. It seems reasonable to presume that the progressive elimination of the domestic water containers through providing piped water supply has largely been responsible for the regression noted in filarial incidence in Western Samoa during recent times.

To recapitulate, endemic filarial infection is widespread in Western Samoa. Microfilaria rates of the different villages are often high, and the elephantiasis rates range from 1 to 5 per cent. From 15 to 25 per cent of the populations of the different villages are subject to periodical attacks of filarial lymphangitis. The vector is Aedes polynesiensis. High natural infection rates have been noted in this mosquito. The vector breeds in small containers like coconut shells, rat-damaged coconuts, tin-cans and domestic rain-water containers. In villages provided with piped water supply or large communal cisterns for rain-water, domestic water containers have been largely eliminated. In such villages, the important sources of Aedes, at the present time, are coconut shells, and other small containers lying in bush near habitations.

The areas of primary importance from the point of view of transmission of filarial infection are in and around the villages. In village areas a high density of the vector occurs because of the profusion of small breeding sites, and maximum opportunities are offered, through close

and constant contact with the human host, for the vector to derive filarial infection from microfilaria carriers and subsequently to transmit the parasite to man. Climatic conditions are favourable for the transmission of filarial infection during all months of the year. It seems likely that the extent of transmission is greater during the period of heavy rainfall (November to April) when the breeding incidence of the vector reaches a high level, than during other months of the year.

There has been a regression in the prevalence of filarial disease and in the severity of its manifestations in Western Samoa during the past four decades. It would appear that this is due to the progressive elimination of the domestic rain-water container, a perennial source of Aedes breeding in the vicinity of habitations, as a result of the provision of piped water supply in a large number of villages, and the erection of communal cisterns for rain-water in many others. In the township of Apia which has an urban aggregation of population, continuous piped water supply and arrangements for refuse collection, facilities for A. polynesiensis breeding are poor and vector density is very low. In this urban area, local transmission of filarial infection appears to be minimal even though there are many microfilaria carriers derived from infections acquired in the rural areas.

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(8) Eastern Samoa

Eastern Samoa, situated between latitudes 11° and 14° S., and between longitudes 171° and 169° W., includes (1) Tutuila, (2) the Manua group, and (3) Swain's Island. Total land area is 77 square miles, and the population is about 21,000. The islands are mountainous and of volcanic origin, with the exception of Swain's Island which is a low island of coral origin. Tutuila, the largest island of the group (area 52 square miles), is about 20 miles in length and 2 to 6 miles in width, with a broken mountain range running along its length. The island is densely wooded, and the 52 villages with a total population of 17,000 are located on patches of level land along the south and west coasts of the island. The villages are of the diffuse type, each house being well apart from the next, and with trees and vegetation all around. Pago Pago, the main settlement, has a quasi-urban aggregation of population.

The three small islands of the Manua group have a population of 3,000. Swain's Island, situated about 200 miles north of Tutuila, and about 100 miles south of Tokelau Islands, is a low coral island consisting of a ring of flat land, about 2 furlongs in width, completely enclosing a shallow lagoon. The land area of the island is about one square mile, and its population of about 100 consists mainly of Tokelau Islanders from Fakaofo and Atafu.

The climate of Eastern Samoa is tropical-oceanic. Temperature and atmospheric humidity are high all through the year. There is little seasonal variation of temperature. Rainfall is very heavy, averaging 196 inches annually, and fairly well distributed over the year; the heaviest amount of rainfall however occurs during November to March.

There are numerous short torrential streams on Tutuila; many of these, especially on the south coast, sink into the porous soil before reaching the sea. Formerly the people depended almost entirely on collected rain-water for drinking and domestic purposes. At present nearly all the villages on Tutuila have piped water supply. The township of Pago Pago was the first to have an efficient system of piped water supply which was completed in 1913. During 1943 to 1945, individual systems of piped water supply were installed for each of the villages on Tutuila Island; a concrete dam or reservoir a little above the base of the hill impounds the water coming down the mountain side, and a piping system conveys the water to outlets in the village. On the islands of the Manua group and on Swain's Island, the people collect and store rain-water in domestic receptacles.

O'Connor (1923) reported that 47.3 per cent of 442 persons (over 15 years) had either microfilaria in blood or clinical signs of filarial disease. From studies carried out during 1928, Phelps et al. (1930) stated that 44 to 64 per cent of adults harboured microfilariae in their blood. Dickson (1943) examined 2171 persons over 4 years of age from 31 villages on Tutuila and found 19.1 per cent positive for microfilaria; the microfilaria rates for the different villages ranged from 12.5 to 38.7 per cent.

According to Jachowski and Otto (1955) the microfilaria rate for ten villages surveyed was 20.3 per cent (2421 persons of all ages examined); Kennedy (1959) examined 5398 persons (all ages) and found 15.9 per cent positive for microfilaria.

The incidence of microfilarial infection in the different age-groups for the rural areas of Tutuila as determined by Dickson (1943) and by Jachowski and Otto (1953) are furnished in Table 15.

TABLE 15

Microfilaria rates in different age-groups in Tutuila

Age group	Number examined	Microfilaria rate
(1) Dickson's (1943) findings		
Under 10	684	3.7
11 to 20	509	9.0
21 to 30	425	20.5
31 to 40	273	27.5
41 to 50	164	26.2
over 50	116	41.3
(2) Jachowski & Otto's (1953) findings		
Under 10	542	6.5
10 to 19	729	13.4
20 to 29	586	26.3
30 to 39	287	33.4
40 to 39	162	36.2
over 49	115	43.5

A census of cases of elephantiasis taken during 1928 by Phelps et al. (1930) showed that there were 669 cases in Eastern Samoa out of a total population at that time of about 10,000; of these, 394 were from Tutuila, and 273 from the islands of the Manua group. Considering that the population of Manua is only about a fourth of the population of Tutuila, the incidence of elephantiasis in Manua must have been very high. Phelps et al. stated that in Eastern Samoa besides attacks of filarial fever which were very common, the physical incapacitation caused by elephantiasis was very considerable; it was mentioned that several persons affected with elephantiasis reached a stage of complete disablement even before they were 50 years of age.

Dickson (1943) recorded an elephantiasis rate of 2.6 per cent in Tutuila (2171 persons examined), and 5.8 per cent among 978 adults; he also reported that 6.3 per cent of males (all ages) had hydrocele. Murray (1948) recorded an elephantiasis rate of 1.3 per cent (5144 persons examined), and Kennedy (1959), 1.0 per cent (5398 persons examined). The elephantiasis rate of 3.6 per cent (Brenneman 1954) was based on the examination of population samples consisting largely of adults.

For the Manua group, we have no recent data. Elephantiasis is believed to be widely prevalent there. The microfilaria rate among Manua islanders residing in Satala village on Tutuila is 30 per cent (Kennedy 1959). The microfilaria rate and elephantiasis rate of Swain's Island are fairly low, 13.5 and 0.9 per cent respectively (Jachowski 1955).

The vector of W. bancrofti in Eastern Samoa is Aedes polynesiensis. Of 3468 specimens of A. polynesiensis examined from native populated areas of Tutuila, 13.2 per cent showed natural infection with W. bancrofti, and 2.6 per cent carried infective stage larvae (Byrd & St. Amant 1959). Other records of the finding of natural infection in A. polynesiensis from Tutuila are: 3.6 to 4.6 per cent (Jachowski & Otto 1952, 1953); and 9.6 per cent (Iyengar 1959b). On Swain's Island, Jachowski (1955) recorded an infection rate of 2.9 per cent in this mosquito.

Aedes polynesiensis breeds in small containers like coconut shells, rat-damaged coconuts, tin-cans, and tree holes, besides domestic rain-water containers. At the present time the domestic water container is not of importance as a breeding site for the vector in the villages of Tutuila, nearly all of which are now provided with piped water supply, and the people do not have to store water. It is of importance as a vector breeding site only in the villages of the Manua group and on Swain's Island where the people depend on collected rain-water for their supply of fresh water, and the householder keeps several receptacles for water. Of the different types of breeding sites of A. polynesiensis in Tutuila, "by far the most common breeding site was the coconut shell" (Jachowski 1954).

The following is a description of the villages on Tutuila Island. "The village is generally built encircling an open area, the 'village green', or along one side of it. The village green is kept closely cropped or even devoid of all vegetation except for fruit trees, flowering shrubs and ornamental plants. Beyond the huts is the jungle. Amid the vegetation at the jungle's edge in the immediate rear of the village is a conglomerate of refuse accumulated over years of refuse disposal. On visiting the village one is impressed with the apparent cleanliness of the area and the absence of mosquito so long as only the village green is visited. To go beyond the fringe of huts, a different story is to be told. In this litter-studded 'backyard', mosquito density is high and ample breeding places are to be found close at hand" (Byrd & St. Amant 1959, p. 68). Byrd and St. Amant found 153 coconut shells on a plot of land measuring 60 feet by 70, and in a second plot, approximately 100 feet square, they found 101 coconut shells. These counts did not take into account the numerous tin-cans and other

breeding sites that were present. In an area of one-tenth of an acre in extent on the backside of Fangasaa village, Iyengar (1959a) collected 350 coconut shells and tin-cans, and on a piece of land ten yards square in the back part of Alofa village, about 150 such containers. The above observations give an idea of the profusion of potential breeding sites of Aedes in the vicinity of habitations on Tutuila.

As rainfall occurs during all months of the year, Aedes polynesiensis breeds in these containers practically uninterruptedly all through the year. There is some seasonal variation in rainfall, but the variation is more in regard to intensity rather than in regard to frequency. There does not appear to be any marked seasonal variation in Aedes breeding. Studies by Jachowski (1954) at Masausi showed that density of A. polynesiensis did not exhibit any definite seasonal variation. The uniformly high temperature and high humidity are favourable for perennial transmission of filarial infection. Byrd and St. Amant (1959) found high rates of natural infection in A. polynesiensis from the village areas during all months of the year, and infective stage larvae of W. bancrofti were found in the infected mosquitoes all round the year. The infection rate in the vector ranged between 9.4 and 18.4 per cent during different months, and the infection rate based on the finding of infective stage larvae ranged between 1.0 and 4.5 per cent. It was shown that the comparatively lower infection rates recorded during some months was due to dilution of the infected vector population by large numbers of freshly bred mosquitoes as a result of heavy rainfall during the preceding month. A similar observation was made in Rarotonga (Cook Islands) by Satchell (1950).

Byrd et al. (1945) and Byrd and St. Amant (1959) from their intensive studies in Tutuila have shown that the villages are the areas where transmission of W. bancrofti infection occurs most commonly. The highest incidence of natural infection occurred among A. polynesiensis caught within the village itself and for a distance of 25 yards around the village; beyond the 50-yard limit, only occasionally was an infected mosquito taken (Byrd et al. 1945, p. 15). To quote: "Within the centre of the village the incidence of infection in the mosquito frequently runs as high as 25 per cent or more. In sections of a few villages the incidence has been found to be as high as 45 per cent. At 25 yards from the periphery of the village the incidence rate drops to 20 per cent or less, and at 50 yards, only a 4 or 5 per cent infection is encountered. At or beyond 100 yards from the village just an occasional infected mosquito is taken. The native village, consequently, is considered a hyperendemic focus of infection. This is conclusively demonstrated by the high incidence of infection in the native population as shown by the finding of microfilariae in the blood stream, the high incidence within the village of mosquitoes infected with demonstrable worms in various stage of development, and the almost complete absence of infection in the mosquito beyond the 100 yard limit from the native village" (Byrd et al. 1945,

Jachowski and Otto (1952, 1953 & 1955) question the correctness the view that the native village is the focus of filarial infection.

observations made on Tutuila, they state that transmission of filarial infection occurs "primarily" in the bush, along the trails and in the plantations", and that "transmission within the village proper is of little concern". This view is based on their calculated "index of transmission", a combination of the two factors, vector density and infection rate in the vector mosquito.

Undoubtedly an index of transmission based on a combination of an estimate of the total vector density and the infection rate in the vector would furnish a reliable criterion for determining the quantum of transmission occurring in any particular locality. Owing to the fact that the vector, A. polynesiensis, rests almost exclusively in bush, it is not feasible to make a reliable estimation of the total density of this mosquito in any one area. Jachowski and Otto base their estimates of vector density on the number of mosquitoes attracted to a human bait during a unit period of time. It will be realized that mosquitoes are attracted to a human bait solely because of the urge to feed. Timed catches on human baits are of value in estimating the density of mosquitoes that are avid for a blood meal and not the total density. The total number of mosquitoes present within the range of attraction of a human bait would include, besides mosquitoes that are hungry, those that have had a blood meal recently and are therefore not avid for a feed. A mosquito that has had a blood meal would not ordinarily feed again until such time as the blood meal has been digested, the ova have matured, and the gravid female has oviposited. During this period of its gonotrophic cycle, the mosquito will not be attracted to a human bait.

The proportion of hungry mosquitoes to the total number present in any particular locality varies inversely as the availability of sources of blood supply within the flight range of the mosquito. In bush away from habitations, because of the lack of readily available sources of blood supply, a high proportion of the mosquitoes present there would be avid for a blood meal. In such areas, timed catches may give high figures depending on the number of mosquitoes waiting for an opportunity to feed. On the other hand, in areas close to habitations, because of the proximity of sources of blood supply, the mosquito has ready access to man the moment it fells the urge to feed. As a result, the proportion of hungry mosquitoes to the total mosquito population in village areas would be very low, and in such areas timed catches on human baits may give low figures even if the total mosquito density is high. Timed catches on human baits therefore would not furnish a reliable estimate of the total density of mosquitoes in a locality.

Estimates of vector density on the basis of timed catches on human baits would be of value only for comparing areas with equal opportunities for the mosquito to obtain a blood meal, as for example in comparing the central part of one village with the central part of another, the peripheral area of one village with the peripheral area of another, or one bush area with another bush area. But if this method is employed for comparing A. polynesiensis densities of areas differing widely in the

opportunities for the mosquito to feed on man, as for example a village area with a bush area away from habitations, it may lead to erroneous conclusions.

This question has been discussed in some detail because of its importance in the epidemiology of filariasis in the Polynesian zone and its bearing on the rationale of filariasis control. It is not contended that transmission of filarial infection does not occur in plantations and bush areas away from habitations. Under certain conditions transmission would certainly occur in plantation areas, as for example when the same areas are visited by man regularly, or if the people camp in any one plantation area for prolonged periods of two weeks or more. Under such conditions the vector population of the particular plantation or bush area has the opportunity of getting infected and, subsequently when the infection in the mosquito has reached the infective stage, to transmit the infection to man. It is known that this happens in several plantation areas as for example of Tokelau, Tuamotu and the northern Cook group. Continued re-infection necessary for hyperfilariation, however, could only occur in areas where there is close and constant contact of high vector density with the human population. From the point of view of the causation of filarial disease in the community, the areas of primary importance are those within and in the immediate vicinity of villages.

There has been a marked regression in the incidence of filarial disease and in the severity of its manifestations in Tutuila during recent times. In 1920, O'Connor (1923) found that 47.3 per cent of persons above the age of 15 showed clinical signs of filarial disease or microfilariae in blood. During 1928, a high proportion of patients attending the hospital in Pago Pago consisted of cases of filarial disease (Phelps et al. 1930). Gross manifestations of filarial disease were, according to these observers, of common occurrence. It was stated that many cases of elephantiasis reached a stage of total disablement even before the age of 50; in many cases of death, filarial disease was noted to be the primary cause of death.

At the present time, gross manifestations of filarial disease in Tutuila are rare. The incidence of elephantiatis has receded appreciably during the past 20 years, from 2.6 per cent in 1942 to 1.0 in 1959. This regression appears to be due to improvements effected in the environmental sanitation of the inhabited areas. In the quasi-urban area of Pago Pago, no local cases of filarial disease have been reported to occur (Sapero & Butler 1945). Gray (1950) stated that "filariasis has never been a problem among persons living in the well-policed naval station (Pago Pago)". Besides the high density of human population in Pago Pago, an efficient system of piped water supply has been in operation there since 1913. The town authorities have also carried out systematic collection of litter for disposal. These measures have been effective in eliminating possible breeding sites of A. polynesiensis in Pago Pago and in keeping vector density at a very low level.

In the rural areas outside Pago Pago, most of the villages are now provided with individual systems of piped water supply. These systems of water supply were installed during the period 1943 to 1945. Prior to that period, the people collected rain-water and stored it in various domestic containers. Phelps et al. (1930) noted the occurrence of large numbers of barrels and other containers for storing rain-water in the villages of Tutuila. During 1943 to 1944 when Byrd & St. Amant carried out their investigations in Tutuila, they noted that rain-water barrels, troughs and cisterns were important breeding sites for *Aedes polynesiensis*. At the present time, the inhabitants of these villages do not have to store water for domestic use. The rain-water receptacles which constituted perennial breeding sites for the vector in the vicinity of habitations have largely been eliminated.

The regression in the incidence of filarial disease noted in Tutuila may be attributed to the elimination of the important breeding sites within the households, namely the domestic rain-water containers, as a result of the provision of piped water supply for the villages of Tutuila.

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(9) Niue

Niue, situated at latitude 19° S., and longitude 170° W., is a small isolated island about 300 miles to the east of Tonga. It is an upheaved coral island rising precipitously from the coast line and forming two limestone terraces, 100 feet and 220 feet respectively above sea level. Niue has an area of 100 square miles and a population of 4,700 distributed in 12 villages, all of which are situated on the coastal edge of the elevated shelf. The interior of the island is wooded and uninhabited. The soil is porous; there are no streams, marshes, or any surface collections of water. Collected rain-water is the only source of fresh water. The householder collects rain-water from the tin roof of his house and stores it in barrels and other receptacles. Some of the villages also have concrete cisterns for rain-water fed from the church roof. Owing to scarcity of fresh water, a common drink of the Niue Islander is the water of young coconuts.

Niue has a sub-tropical climate. Mean monthly maximum temperature rarely rises above 85° F. The mean monthly minimum temperature ranges between 74° and 65° F. There is considerable diurnal as well as seasonal variation in temperature. There is appreciable difference in temperature between the summer months (December to February) and the winter months (June to September). Because of the island's elevation and its extremely porous substratum, atmospheric humidity is low, particularly during the dry months, May to October. Rainfall is on the average 79 inches annually. Most of the precipitation occurs during December to March. During the dry season, extending from May to October, there is ordinarily little rainfall, and frequently this period is marked by severe drought.

Iyengar (1958) examined 586 persons (all ages) and found that 2.6 per cent had elephantiasis. The part of the body most commonly affected was the leg. All the cases were of the mild type. Cases of multiple lesions were rare. The hydrocele rate among males of all ages was 1.9 per cent, and among adult males, 3.4 per cent. Iyengar noted that 7 per cent of the population of Niue were subject to periodical attacks of filarial lymphangitis. In comparison with the majority of the Polynesian islands, the general incidence of filarial disease in Niue is low. According to the official report for the year 1957, there were 36 cases of elephantiasis of the leg among the total population (4,600) of Niue, (crural elephantiasis rate of 0.8 per cent). McCarthy (1959) stated: "In Niue, though some 20 per cent of the adult population of the village of Mutalau demonstrated microfilaraemia, indigeneous clinical filariasis was extremely uncommon". This author stated that the common age of onset of elephantiasis among males in Niue was quite high, namely 55 to 65 years.

The type of filarial infection in Niue is the non-periodic *W. bancrofti*. Microfilaria counts made over a 24-hour period from a carrier in Niue are furnished in Table 16.

TABLE 16

Microfilarial density at different hours of the day
in a carrier from Niue (after Iyengar 1958)

Hour	Microfilaria count in 20 cmm. of finger blood
1400	52
1600	46
1800	41
2000	39
2200	54
2400	39
0200	34
0400	31
0615	30
0800	44
1000	26
1200	49

The incidence of W. bancrofti infection in Niue is not unduly high. During 1954, 22.2 per cent of 748 adults examined were positive for microfilaria in blood (Report, Department of Island Territories, New Zealand, 1955). On the basis of the microfilaria rate of 22 per cent for adults, the rate for the total population may be estimated at 16 per cent. In 1956, subsequent to mass treatment of the population with diethylcarbamazine, the microfilaria rate for persons over 5 years of age was 3 per cent (Simpson 1957), and 2.7 per cent for the entire population during 1957 (Iyengar 1958).

The vector of non-periodic W. bancrofti in Niue is probably Aedes (Stegomyia) cooki. This is the only species of the Aedes scutellaris group present in Niue. Iyengar (1958) examined for natural infection with W. bancrofti, 87 specimens of this mosquito collected from different villages in Niue and obtained negative results. This study was carried out during the dry cold season when mosquitoes were few, and the temperature and humidity conditions were not favourable for the development of the parasite in the mosquito host. The negative findings are therefore inconclusive.

Aedes cooki, like its ally, A. polynesiensis, breeds in cisterns and barrels for storing rain-water, coconut shells, and tin-cans. Domestic water containers are the most important breeding sites of A. cooki in the village areas. Every house has one or more receptacles for storing water. In bush near habitations, coconut shells are seen often in large numbers. These include coconuts opened for coconut water as well as those opened for making copra. The former are the more prolific breeding

sites for Aedes as they contain food matter. The breeding of Aedes in these small containers is however largely restricted to the wet season. The prevalence of A. cooki in Niue is subject to marked seasonal variation. Breeding incidence is high during the summer months when temperature is high and rainfall is more frequent. During the winter months, its breeding incidence is low. Rat-damaged coconuts are not important as breeding sites for Aedes on Niue. Rats do not cause any appreciable damage to coconuts here. The domestic cat which has run wild in Niue and infests the bush and plantation areas appears to be responsible for keeping the rat population under control.

Unlike most of the Polynesian islands, conditions on Niue are not favourable for perennial transmission of W. bancrofti infection. The transmission season appears to be restricted to the summer months when rainfall is heavy and vector breeding reaches a peak incidence. The high temperature and high humidity prevailing during this period are favourable for the development of the filarial parasite in the mosquito host and for the transmission of the infection. From May to October, rainfall is scanty and the extent of vector breeding is very low. Besides the low prevalence of Aedes mosquitoes during this season, the low temperature and low humidity are unfavourable for transmission of W. bancrofti. Mean temperature during this period ranges between 68° and 70° F., and the minimum temperature often drops to as low as 55° F. The comparative low incidence of filarial disease in Niue may possibly be due to the absence of perennial transmission, and consequently the reduced chances of hyperfilariation in man.

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(10) Cook Islands

The Cook Islands lie between latitudes 8° and 23° S., and between longitudes 156° and 167°W., and comprise 15 islands with a total land area of 90 square miles. The islands fall under two topographically distinct groups. The Northern Cook group comprises 7 small low islands of coral origin, namely Penrhyn, Rakahanga, Manihiki, Palmerston, Pukapuka, Nassau and Suwarrow (of which the last two are not inhabited), with a land area of 13 miles and a population of about 2,500. The southern group consists of 8 large high islands of volcanic origin, six of which are inhabited, namely Aitutaki, Atiu, Mangaia, Mauke, Mitiaro and Rarotonga; the total land area of the southern group is 77 square miles and the population is about 14,000. Rarotonga, the principal and largest island of the group (area 26 square miles), has a population of 7,400.

Climate in the northern group is tropical-oceanic, and in the southern group, tropical to sub-tropical. Rainfall averages 80 inches annually. The islands of the northern group, being low islands, do not derive much rainfall from the trade winds, with the exception of Pukapuka, the most westerly island of the group, which gets as much as 120 inches of rainfall in the year. Summer is the period of maximum rainfall. Atmospheric humidity is high practically all through the year.

All the villages on Rarotonga Island are served with piped water supply from reservoirs in the hills. Three small villages on Aitutaki have piped water supply pumped from a deep well. In all other areas, the people depend on collected rain-water for their supplies of fresh water. Some of the villages have communal cisterns for rain-water, but in many cases the supply is inadequate and the people have to collect rain-water and store it in domestic containers.

Non-periodic W. bancrofti infection is widespread in the Cook Islands. The two groups of the Cook Islands differ markedly in regard to the incidence of filarial disease. In most of the islands of the southern group a high incidence of filarial disease prevails, whereas the majority of the islands of the northern group are practically free from filarial disease. These two groups are discussed separately.

Southern Cook Group

The recorded data on the microfilaria rates of the islands of the southern group are furnished in Table 17.

TABLE 17

Microfilaria rates of the islands of the Southern Cook group

Area	Number examined		Microfilaria rate	Authority
Aitutaki	609	(all ages)	29.2	McCarthy 1959a
Aitutaki	240	(over 9 years)	42.5	Davis 1949
Aitutaki:				
Ureia	199	(all ages)	22.1	Iyengar 1957
Amuri	261	"	18.0	"
Vaipae	220	"	17.7	"
Tautu	184	"	17.9	"
Nikaupara	172	"	27.9	"
Reureu	95	"	24.2	"
Arutanga	166	"	22.3	"
Total:	1297	"	20.9	"

Table 17 (Cont'd)

Area	Number examined		Microfilaria rate	Authority
Rarotonga	1890	(all ages)	22.3	McCarthy 1959a
Rarotonga:				
Titikaveka	191	"	19.9	Iyengar 1957
Ngatangiia	253	"	23.7	"
Arorangi	110	"	28.2	"
Total:	554	"	23.3	"
Atiu	459	"	15.3	McCarthy 1959a
Mauke	215	"	21.4	"
Mangaia	131	-	26.0	Lambert 1926
Mitiaro	34	-	58.8	"

The microfilaria rates of the islands of the southern Cook group range between 15 and 29 per cent. The high microfilaria rate of 58.8 per cent recorded for Mitiaro (Lambert 1926) is probably based on the examination of a small sample of adults. The general incidence of filarial infection is high. Areas with sensible aggregation of population have low filarial endemicity. McCarthy observed that in the township of Avarua, the headquarters settlement on Rarotonga, where nearly half of the total population of that island live, filarial endemicity is of a very low order.

Filarial infection has been noted to be common even among young children. In Aitutaki, McCarthy found 4 per cent of children under 5 years of age, and 10 per cent of children of the age group 5 to 9 years positive for microfilaria in peripheral blood. For Aitutaki and Rarotonga taken together, microfilaria rates among children aged 1 to 4 years, and 5 to 9 years, were respectively 2.5 and 10.4 per cent (Iyengar 1957); Iyengar recorded the finding of microfilaraemia in a child aged 18 months from Ureia village on Aitutaki Island, and this finding was confirmed by a second examination of the same child.

Filarial disease is very common in the islands of the Southern Cook group, with the exception of Mitiaro. The data on the incidence of elephantiasis in the different islands are presented in Table 18. High elephantiasis rates prevail in the majority of the islands of the southern group. In several villages in Aitutaki and Rarotonga, as also in Mauke Island, elephantiasis rates are higher than 4 per cent. Multiple lesions in cases of elephantiasis are of frequent occurrence. As many as 34 of the 72 cases of elephantiasis recorded by Iyengar (1957) from Aitutaki and Rarotonga showed more than a single lesion. The incidence of elephantiasis among females was higher (4.3 per cent) than among males (3.5 per cent, even inclusive of scrotal elephantiasis).

TABLE 18

Elephantiasis rates of the islands of the southern Cook group

Area	Number examined		Microfilaria rate	Authority
Aitutaki	528	(all ages)	4.2	McCarthy 1959a
Aitutaki:				
Ureia	199	(all ages)	6.5	Iyengar 1957
Amuri	261	"	1.1	"
Vaipae	220	"	4.1	"
Tautu	184	"	3.3	"
Nikaupara	172	"	5.2	"
Reureu	95	"	5.3	"
Arutanga	166	"	1.8	"
Total:	1297		3.7	"
Rarotonga	358		2.9	McCarthy 1959a
Rarotonga:				
Ngatangiia	253	(all ages)	5.9	Iyengar 1957
Titikaveka	191	"	2.1	"
Ngatangiia	253	"	5.9	"
Arorangi	110	"	4.5	"
Total:	554	"	4.3	"
Atiu	900	"	2.4	Lambert 1926
Mauke	560	"	4.1	"
Mitiaro	180	"	0	"
Mangaia	"Cases of elephantiasis present"			Iyengar 1957

The vector of W. bancrofti in the Cook Islands is Aedes polynesiensis. High rates of natural infection in this mosquito have been recorded from Aitutaki and Rarotonga where detailed studies have been carried out. Among mosquitoes caught within or near human habitations, the natural infection rates recorded are as follows: 6.0 per cent (McKenzie 1925); 9.1 per cent (Satchell 1950); 13.4 per cent (Iyengar 1957); 11.3 per cent in Aitutaki and 2.8 per cent in Rarotonga (McCarthy 1959a).

Vector density in the villages of the southern Cook group is usually very high. The main breeding places of the vector are cisterns and barrels for storing rain-water, coconut shells and tin-cans. Except on Rarotonga Island where all the villages are provided with piped water supply, the people depend on collected rain-water for their fresh water supply. The domestic receptacles for storing water constitute perennial breeding sites for the Aedes mosquito. In several areas, concrete cisterns have been erected for rain-water; even these were found to breed A. polynesiensis in large numbers, as the cisterns are not of the sealed

type. Large number of temporary breeding sites like coconut shells and tin-cans are to be found in the bush in the backyards of houses. In the villages of Rarotonga Island, Amos (1946) reported the finding of "an astounding number" of discarded tin-cans, coconut shells and bottles in the bush adjoining habitations; Davis (1949) stated that tin-cans and coconut shells were always found in large numbers in bush near native houses. Another prolific breeding site for Aedes is the rat-damaged coconut. On all the islands, with the exception of Aitutaki, rats cause considerable damage to coconuts, estimated at 50 to 80 per cent of the total coconut crop (Iyengar 1957). In areas where the habitations are situated in the midst of, or in close proximity to, coconut plantations, the rat-damaged coconut is an important factor in the epidemiology of filariasis.

The extent of breeding of Aedes in the temporary breeding sites is subject to seasonal variation depending on the rainfall. In Rarotonga Davis (1949) observed that during April to November, vector density was low owing to lack of persistent rainfall to keep the breeding sites constantly filled with water, and the low temperature (about 65° F.) which prolonged the duration of the larval stages; vector density was found to be much higher during December to March when temperature is high (80° to 90° F.) and rainfall is heavy and continuous.

Satchell (1950) made some very interesting observations in Ngatangiia village (Rarotonga) which show that the infection rate in the vector mosquito is in a state of fluctuation, dropping after the emergence of batches of mosquitoes following heavy rainfall, and steadily rising again as the young mosquitoes acquire filarial infection. It was observed that during December, following a period of dry weather, the density of the vector mosquito in Ngatangiia village was 17 (average per collection) and the infection rate in the vector was 13 per cent. Two weeks after heavy rainfall, the average number of mosquitoes per collection rose to 39, and the infection rate dropped to 1.6 per cent. The increase in vector density was due to emergence of large numbers of mosquitoes as a result of increased facilities for breeding consequent on the heavy rainfall; the lowering of the infection rate in the mosquito was brought about through dilution of the infected mosquito population by freshly emerged mosquitoes which have not had a chance as yet of getting infected. During the two weeks that followed, the infection rate in the vector rose steadily to 3.2 and 12.8 per cent respectively. During the last week of study, when conditions became fairly stabilized, the infection rate dropped to 9.6 per cent while vector density remained steady at 52.

Observations by several workers in the Cook Islands indicate that transmission of filarial infection occurs primarily in the vicinity of habitations. Davis (1949) failed to find filarial infection in mosquitoes caught in plantation areas, while infected mosquitoes were invariably found in collections made within the villages. Satchell (1950) made a comparative study of vector density and the incidence of filarial infection in the vector in three different locations in Ngatangiia villages, namely (1) inside houses, (2) within a radius of 25 yards from houses, and (3) in plantations regularly visited by the people but away from habitations. For these three locations, vector densities were 23, 31 and 55 respectively, and the corresponding infection rates in the vector were 9.1, 6.9, and 1.6 per cent. Taking into consideration both the abundance of the vector mosquito and the incidence of infection, there were 2.4 times as many infected mosquitoes in houses as in plantations visited by the people.

McCarthy (1959a) states: "Observations both in Rarotonga and Aitutaki indicate that mosquito infectivity is very patchy in its intensity, being highest where mosquito and human habitations are closely adjacent or co-extensive, a state of affairs for which the short flight range of Aedes polynesiensis is chiefly responsible. This short flight range normally militates against wide dispersal of infected mosquitoes from a particular focus of infection". On the islet of Akaiami in Aitutaki lagoon where the only permanent resident was a person with moderate microfilaraemia, 25.9 per cent of A. polynesiensis caught in the vicinity of his quarters were infected while none of those caught at a distance of 200 yards or more was found infected (McCarthy 1959a).

Iyengar (1957) from studies made in Rarotonga and Aitutaki stated: "Transmission of filarial infection occurs primarily in the vicinity of habitations. High infection rates were noted in Aedes polynesiensis collected in and around houses in comparison with infection rates in mosquitoes caught even at a distance of 100 yards from habitations. Specimens collected inside houses often showed full-grown filaria larvae of the infective stage in the head and labium of the mosquito, indicating that transmission occurs even inside the house. It is also not unusual to find multiple infections with two or three broods of filaria larvae in mosquitoes caught within the village. On the other hand, in mosquitoes caught at a distance of over 100 yards from habitations, stray infections were noted but never was a multiple infection recorded.

"The finding of filarial infection in very young children also supports the conclusion that transmission occurs in habitations or in their immediate vicinity. In the vicinity of habitations the vector mosquito has close contact with the reservoir of infection as well as with the recipient. As this mosquito has a limited range of flight, such contact is not frequent in areas away from human habitations. While it is possible that stray instances of transmission may occur in areas away from habitations, an epidemiologically significant amount of transmission occurs only in the immediate vicinity of houses".

Although Aedes polynesiensis rests primarily in bush, it frequently enters houses to feed on man, especially when breeding sites occur close to houses. In Aitutaki, large numbers of this mosquito were seen feeding on man inside living rooms and bed-rooms. In the large veranda of a house in Aitutaki, 22 A. polynesiensis mosquitoes

were found feeding on the legs of a boy aged 5 years. On the same island, Laird (1954) collected this mosquito "while attempting to bite during the hours of daylight, both in areas of dense vegetation and inside houses at the villages". Satchell (1950) observed that in the villages on Rarotonga, "many (A. polynesiensis) mosquitoes do in fact lurk in houses, in shady places such as under furniture, particularly beds, and in the crevices of Kikou thatch". House infestation by Aedes polynesiensis is common where breeding sites occur close to houses.

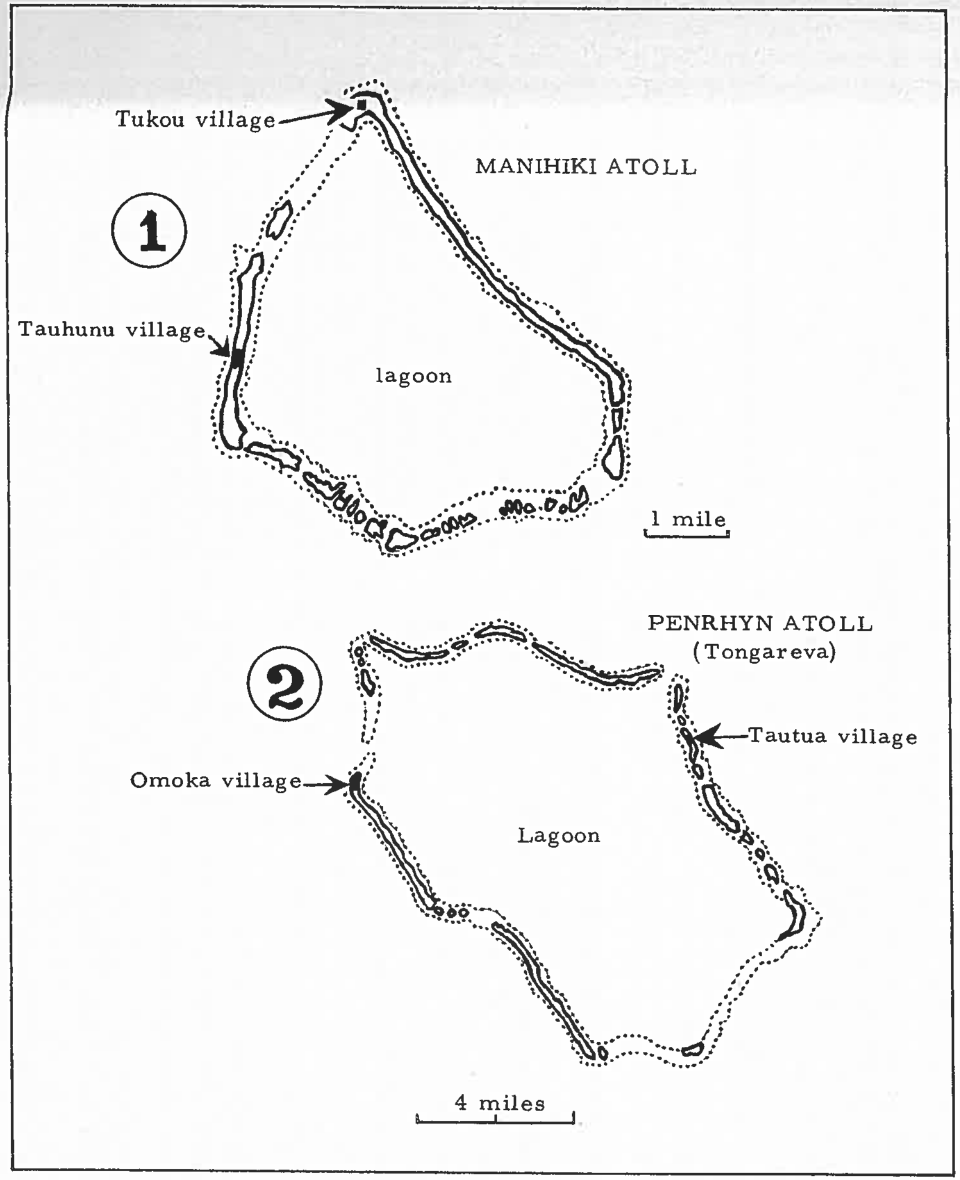
Under certain conditions, transmission of filarial infection would occur in plantations, as for example when a plantation area heavily infested with A. polynesiensis is regularly visited by the people, or when they camp in such plantations long enough (two weeks or longer) for the infection acquired by the mosquito to develop to the infective stage. Under those conditions, the infection would spread and, as a result, a significant proportion of the population would show microfilaraemia. Judged from findings in several areas, the extent of transmission under such conditions of discontinuous or interrupted contact with the vector, while capable of producing microfilaraemia in the population, does not ordinarily suffice to produce hyperfilariation necessary for the onset of filarial disease. This feature is illustrated by a consideration of the islands of the Northern Cook group.

Northern Cook Group

Among the low coral islands comprising the Northern Cook group, two distinct types can be made out: (a) Penrhyn, Manihiki, Rakahanga and Palmerston are typical atolls, each consisting of a ring of many small and very narrow islets, about one to two furlongs in width, placed around a deep and spacious lagoon; (b) Pukapuka is a reef island consisting of a very small number of broad islets, about a mile across in all directions. These two types of islands of the Northern Cook group are strikingly different as regards filarial endemicity.

(a) Atoll islands - Penrhyn, Manihiki, Rakahanga and Palmerston

Penrhyn (Map 11,2) is the largest atoll of the group, about 12 miles long, and 6 to 8 miles in width, and composed of a ring of numerous narrow islets along a reef about 40 miles in circumference, surrounding a lagoon of about 108 square miles. Many of the larger islets of this atoll were formerly inhabited, and "maraes" are found on some of them. About the year 1864, Peruvian slavers raided these villages and carried off over 1,000 men, women and children as slaves, most of whom died abroad (Te Rangi Hiroa 1932). The remnant of the population of Penrhyn atoll subsequently congregated on two small islets, Omoka and Tautua, which are the only ones at present inhabited; the total population of Penrhyn is 650.



MAP 11. Manihiki (1) and Penrhyn (2) atolls (Northern Cook group)

Manihiki atoll (Map 11,1) is about $5\frac{1}{2}$ miles long and 5 miles in greatest width, with a land area of about 2 square miles. Of the numerous islets comprising this atoll, only two, namely Tauhunu and Tukau, are inhabited. The two villages together have a population of about 700.

Rakahanga atoll is $2\frac{1}{2}$ miles long and $1\frac{1}{2}$ miles in width, with a land area of about 2 squares miles. The entire population of the atoll numbering about 350, live in a small compact village on an islet in the southwestern part of the atoll.

Palmerston atoll has about 6 small sandy islets aroung a lagoon about 7 miles in length and 5 miles in width. Its population of about 80 live on a single islet in the western part of the atoll.

In each of these atolls, the population is concentrated in a single village settlement, or in two such settlements. All other islets are uninhabited and are reserved for growing coconut and food crops. The islets are narrow, generally about one furlong in width. The villages are compact, with houses close to one another, practically free from bush and rank vegetation, and free from litter likely to serve as breeding places for mosquitoes. All accounts of the villages of these atolls mention the scrupulously tidy condition of these villages. Robson (1959) says that the manner in which these settlements are maintained "might well be an object lesson to many more highly civilized communities". The villages are provided with large metal tanks or concrete cisterns of 5,000 to 10,000 gallon capacity for storing rainwater, using the roofs of public buildings and churches as catchment. The village of Omoka in Penrhyn atoll also has a piped water supply down the main street of the village. There is generally no need for the people to collect and store rain-water in domestic receptacles. The villagers obtain their daily supplies of fresh water from the communal cisterns which are of sufficiently large capacity to meet the requirements of the small populations of these villages.

Few opportunities are offered for the breeding of Aedes polynesiensis in the villages. As communal cisterns have been provided, the people do not have to store rain-water in domestic receptacles. The village areas are also free from litter like coconut shells. In the absence of suitable breeding sites, the incidence of A. polynesiensis in the villages is extremely low. Consequently, the chances of transmission of filarial infection in the villages are poor.

On the plantation islets, on the other hand, a high density of prevalence of the vector mosquito occurs everywhere. Large numbers of rat-damaged coconuts lie on the ground in the plantations; these are prolific breeding sites for Aedes. From time to time, the people visit the plantation islets for collecting copra, and after a brief stay, rarely lasting more than one week, return to the village islet. In spite of the high vector density prevailing in the plantations, if the collecting party does not stay in any one plantation area longer than the period of incubation of the filaria parasite in the mosquito host, transmission of the infection is not likely to occur. Whenever the people happen to camp in one part of a plantation for longer periods, or if they visit the same area regularly, they would be exposed to infection. That this happens frequently is shown by the presence of microfilaraemia in the populations of these atolls.

Table 19 furnishes the recorded microfilaria rates of Penrhyn, Rakahanga, Palmerston and Manihiki atolls. Manihiki is the only atoll with a high microfilaria rate (19.7 per cent) whereas in all others the microfilaria rates are less than 9 per cent. However, it has been found that in all the four atolls the intensity of infection in the microfilaria carriers is very low. The low incidence of filarial infection in the majority of the atolls and the low grade infection noted in carriers from each of the four atolls are due to the fact that the people are not continuously exposed to infection. On the village islets where the people live, transmission of filarial infection does not appear to be feasible owing to the virtual absence of the vector mosquito. On the plantation islest visited by the people from time to time, transmission of infection does occur under certain conditions, but exposure to infection is intermittent and not intensive because the people do not stay in contact with high vector density for any prolonged periods.

TABLE 19

Microfilaria rates and elephantiasis rates (all ages) of the islands of the Northern Cook group

Island	Number examined	Micro-filaria rate	Number examined	Elephan-tiasis rate	Authority
1. Atolls					
Penrhyn	274	5.8	-	0	McCarthy 1959a
Rakahanga	226	8.4	-	0	"
Palmerston	69	8.7	-	0	"
Manihiki	371	19.7	-	0	"
2. Reef Island					
Pukapuka	218	29.4	-	-	McCarthy 1959a
"	440	28.4	498	3.8	New Zealand Med. Res. Report

That exposure to filarial infection is possible only on the plantation islets and not in the villages of these atolls is further shown by the following observations. The children spend most of their time on the village islets, and it is only very rarely that we find filarial infection

in them. None of 136 children under 5 years of age examined from all the four atolls taken together (Table 20) showed microfilaraemia (McCarthy 1959a). Only 4 out of 147 children aged 5 to 9 years were positive for microfilaria in peripheral blood; all the four positives of this age group are from Manihiki which has a high microfilaria rate of 19.7 per cent, in comparison with the other atolls. As the produce collecting parties consist mostly of adults, the infection rate is markedly higher in the older age groups than in the younger age groups. As the collecting parties consist very largely of males, and as the majority of the women stay in the village and only occasionally go to the plantations, women are less exposed to infection than the menfolk; in each of the four atolls, the microfilaria rate among adult males is much higher than among adult females (McCarthy 1959a).

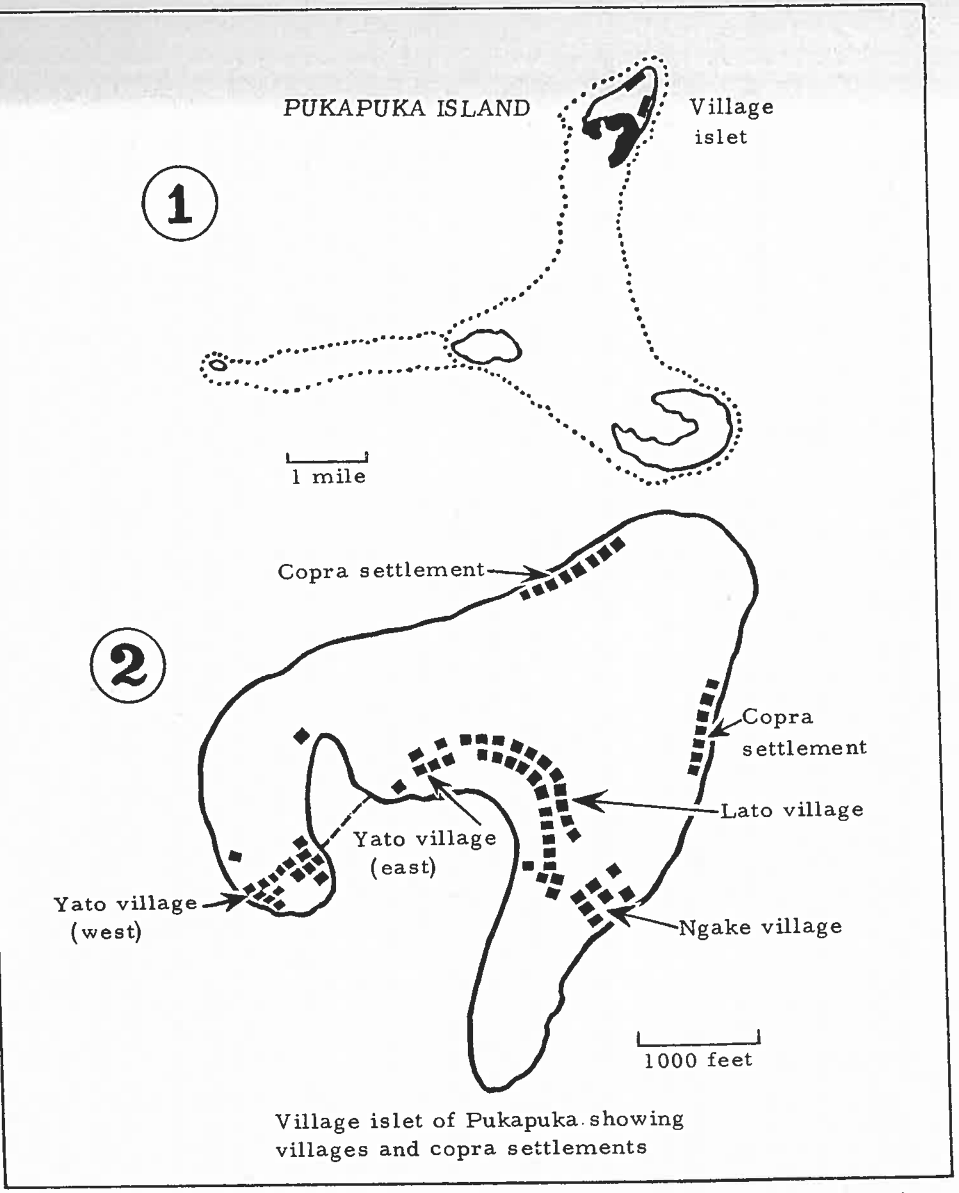
TABLE 20

Incidence of microfilaraemia by age groups for the islands of the Northern Cook group (after McCarthy 1959a, and for the last entry after Report, New Zealand Medical Research).

	Under 5 years		5 to 9 years		10 to 19 years		20 years & over	
	Number exa-mined	Micro-filaria rate	Number exa-mined	Micro-filaria rate	Number exa-mined	Micro-filaria rate	Number exa-mined	Micro-filaria rate
Atolls								
Penrhyn	43	0	50	0	55	5.5	126	10.3
Rakahanga	20	0	21	0	48	6.3	137	11.7
Palmerston	14	0	16	0	12	8.3	27	18.5
Manihiki	59	0	60	6.7	67	16.4	185	31.4
Total	136	0	147	2.7	182	9.9	475	19.4
Reef Island								
Pukapuka	34	5.9	20	10.0	44	22.7	120	41.7
	Under 6 years		6 to 10 years		11 to 20 years		21 years & over	
Pukapuka*	19	26.5	66	10.6	152	24.2	202	37.6

A remarkable feature is the total absence of filarial disease in the populations of the four atolls, in spite of the presence of demonstrable microfilaraemia in a significant proportion of the population. No cases of elephantiasis or other manifestations of filarial disease have been observed

*After Report, New Zealand Medical Research.



MAP 12. Pukapuka Island (1) and Pukapuka islet (2) (Northern Cook group)

to occur among the populations of these atolls (Knott 1944; McCarthy 1959a and 1959b). Even in Maniki with a microfilaria rate of 19.7 per cent for the total population and 31.4 per cent for adults, cases of filarial disease are unknown. McCarthy (1959a) says: "No indigenous elephantiasis or major clinical filariasis has yet been noted in Manihiki". As the people of these atolls are not continuously exposed to infection and re-infection, little opportunity is offered for hyperfilariation in the human host and, in consequence, filarial disease is practically absent. Conditions here are analogous to those in Tokelau Islands discussed earlier.

(b) Reef island - Pukapuka

Pukapuka island (Map 12, 1) comprises three large islets closely planted with coconut palms and overgrown with dense bush. Of the three islets, only the northern islet known as Wale or Pukapuka islet is inhabited; the other two islets are visited occasionally for copra collection. Pukapuka islet (Map 12, 2) is a compact mass of land, about one mile in length and one mile in width. Within this broad islet with luxurient vegetation are located four villages with a total population of 640.

The inhabited islet of Pukapuka is different from the inhabited islets of the atoll islands discussed above. The villages are heavily infested with Aedes polynesiensis. This mosquito occurs in large numbers even inside houses. From a search of 78 households in Pukapuka, 811 specimens of A. polynesiensis were collected (New Zealand Medical Research). In the peri-domestic areas as also in the plantations, vector density is extremely high. Numerous breeding sites of A. polynesiensis occur everywhere. The village areas as well as the plantations are littered with large numbers of shells of coconuts opened for copra, coconuts opened for coconut water, and rat-damaged coconuts; the last two are prolific breeding sites for Aedes. The heavy rainfall (120 inches annually) in Pukapuka keeps these breeding sites constantly filled with water, and favours continuous breeding of the vector all through the year. The villages, the copra settlements, and the coconut plantations (Map 12, 2) are contiguous to one another. As A. polynesiensis occurs in large numbers everywhere on Pukapuka islet, the people are in contact with high vector density wherever they may be on this islet, in their homes and in the peri-domestic environment, as well as in the copra settlements and the coconut plantations which they visit daily. In each of these situations the local vector population has the opportunity to get infected from the human reservoirs, and in turn to transmit the infection to man. The people are thus exposed to intensive transmission all the time, and opportunities for hyperfilariation are high. This would account for the high filarial endemicity of Pukapuka. The microfilaria rate (all ages) is as high as 29.4 per cent (McCarthy 1959a). Filarial disease is very common. The elephantiasis rate for all ages is 3.8 per cent, and for persons 16 years of age and over, 6.1 per cent (New Zealand Medical Research). Filarial affection of the genitals is extremely common among adult males; 34.8 per cent of males aged 16 years or over showed genital filariasis. Filarial infection is of frequent occurrence even among very young children. According to Report, New Zealand Medical Research, a high microfilaria rate (26.5 per cent) was recorded in the age group under 6 years (Table 20); in the later age groups the microfilaria rates are: 6 to 10 years, 10.6 per cent; 11 to 20 years, 24.2 per cent. *McCarthy (1959a) recorded microfilaria rates of 5.9, 10, and 22.1* per cent respectively in the age groups under 5, 5 to 9, and 10 to 19 years.

These observations bring out the striking difference between the filarial endemicity of the four atoll islands, Penrhyn, Rakahanga, Manihiki and Palmerston on the one hand, and that of the reef island, Pukapuka, on the other. In the former, microfilaria rates (all ages) range between 6 and 20 per cent, the intensity of infection in the carriers is low, children under 10 years of age are practically free from filarial infection, and filarial disease is unknown. In Pukapuka, the microfilaria rate is 29 per cent, 7.4 per cent of children under 10 years of age (and 14.1 per cent according to Report, New Zealand Medical Research) are positive for microfilaria in blood, and filarial disease is very common and has been known to have existed there for many generations; elephantiasis rate (all ages) is 3.8 per cent (6.1 per cent among adults), and the genital filariasis rate among males over 15 years of age is 34.8 per cent. This marked difference in filarial endemicity of the two types of islands of the Northern Cook group is due to the fact that the people of the atoll islands are free from exposure to infection in their village environment, and although exposed to the infection during their brief visits to the plantation islets, the chances of establishment of hyperfilariation are extremely low. In Pukapuka, on the other hand, the people live in close and continuous contact with high vector density all the time, whether in their houses, in the peri-domestic areas, or in the plantations. They are thus exposed to continuous and intensive infection and re-infection, and the chances of establishment of hyperfilariation in the human host are high. This is reflected in the high incidence of elephantiasis and other manifestations of filarial disease.

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(11) Society Islands

The Society Islands lie between latitudes 16° and 18° S., and between longitudes 148° and 150° W. All the eight inhabited islands of the group are high islands of volcanic origin, rising to elevations of several thousand feet and characterized by jagged peaks, steep cliffs, deep valleys and dense vegetation. The inhabited areas on these islands are restricted to the narrow coastal belt, the rugged mountainous areas in the interior being uninhabited. The total land area is 640 square miles, and the total population about 55,000. Tahiti, the largest island of the group with an area of about 400 square miles, has a population of 36,000, of which nearly half (17,000) live in the town of Papeete. The rest of the population of Tahiti live in a more or less continuous village on the narrow coastal strip which is closely planted with coconut palms, breadfruit trees and other vegetation. On the other islands of the Society group also, the villages are situated on the narrow flat coastal areas in the midst of extensive coconut groves.

The climate of the Society Islands is hot and humid all round the year. Mean annual temperature is 80° F. There is little of seasonal variation of temperature. Annual rainfall averages 72 inches. Most of the rainfall occurs during the summer months, December to March, and the least during July and August. Rainfall is heavier on the windward side of the islands than on the leeward side. Atmospheric humidity is very high.

Formerly, the people of the Society Islands depended largely on collected rain-water for their supplies of fresh water. At the present time, most of the inhabited areas are provided with piped water supply. The town of Papeete has an efficient system of piped water supply which was installed in 1913. Since 1928, piped water supply systems have been installed progressively on the different islands of the group, and at the present time nearly all the villages on Tahiti and Moorea, and the majority of the villages (about three-fourths of the total population) of the Leeward Islands have the benefit of piped water supply. In a relatively small number of areas, even at the present time, the people depend on collected rain-water for drinking and domestic purposes.

Non-periodic W. bancrofti infection has a wide distribution in the Society Islands. The data on microfilaria rates for the eight inhabited islands of the group during the period prior to the inauguration of the scheme for mass chemotherapy with diethylcarbamazine are set out in Table 21. In the vast majority of the rural areas, the microfilaria rates (all ages) are higher than 25 per cent. In many of the villages of Tahiti, very high microfilaria rates ranging between 35 and 44 per cent have been recorded, as for example Hitiaa, Mahaena, Mahina, Mataiea, Papara and Tiarei. The intensity of infection in the microfilaria carriers is generally high. Bambridge (1960) showed that the average microfilaria count in 20 cmm. of blood per positive was 79.6 for the districts of Tahiti taken together.

In contrast to the high microfilaria rates of the rural areas of Tahiti, the town of Papeete has a comparatively low microfilaria rate of 11.8 per cent (Table 21). Even this figure appears to be unduly high considering conditions prevailing in Papeete. It seems probable that most of the microfilaria carriers encountered in Papeete during the 1955 survey were not locally contracted infections and that the vast majority of these persons were imported cases from the endemic rural areas of Tahiti. The town of Papeete has a high density of population, an efficient system of piped water supply which has been functioning for over 50 years, and conservancy arrangements for collection and disposal of refuse. Opportunities for the breeding of the vector mosquito, Aedes polynesiensis, are poor, and vector density is extremely low. For instance, during the investigations carried out during 1955, the total number of A. polynesiensis caught from 465 catching stations in Papeete was only 61, an average of 0.13 per catching station (Laigret 1959). In 420 of the 465 catching stations, not even a single mosquito was taken. Under such conditions of extremely low vector density, transmission of filarial infection seems virtually impossible. In Papeete, as in some other urban areas within the Polynesian zone having high population density, piped water supply and proper disposal of litter, cases of locally contracted filarial infection are probably very few, if not altogether non-existent. It seems likely that the vast majority of the infections recorded in Papeete are imported carriers from the rural areas of Tahiti where filarial infection is highly endemic, and not indigenous to the town of Papeete. Tahiti is a small island, and Papeete is within easy reach of the rural areas; there is constant movement of people from the rural areas of Tahiti into Papeete and vice versa.

The incidence of filarial infection and the average intensity of infection in microfilaria carriers in the different age groups for the rural districts of Tahiti taken together, based on data kindly furnished by Bambridge (1960), are set out in Table 22. In Tahiti, filarial infection is common even among very young children; 7.1 per cent of children under 5 years of age, and 14.4 per cent of children aged 5 to 9 years, were positive for microfilariae in peripheral blood. The microfilaria rate rises to 25 per cent in the age group 10 to 19, and to 36.3 per cent in the age group 20 to 29. In the later age groups, the microfilaria rates range between 41 and 43 per cent.

TABLE 21

Microfilaria rates (all ages) of the different areas in the Society Islands prior to mass chemotherapy.

Area and year of observation	Number examined	Microfilaria rate	Authority
Tahiti: rural			
15 districts (1949)	3,390	37.9	March et al. 1960
Tahiti: rural			
All districts (1949)	11,928	30.2	Bambridge 1960
Tahiti: rural (1949-1950)			
Afaahiti	472	25.2	Beye et al. 1953
Arue	717	29.1	"
Faaone	276	34.1	"
Hitiaa	231	43.6	"
Mahaena	148	36.4	"
Mahina	601	35.2	"
Mataiea	593	38.0	"
Papeari	659	30.2	"
Pirae	1,055	29.8	"
Paea	916	30.3	"
Pueu	391	31.1	"
Papenoo	390	32.5	"
Punaauia	849	31.6	"
Papara	884	35.2	"
Tiarei	355	39.6	"
Tahiti: urban (1955)			
Papeete	13,608	11.8	Laigret 1959
Moorea (1954)			
Papetoai	294	24.2	Laigret 1959
Afareaitu	550	27.7	"
Teavaro	298	27.2	"
Haapiti	524	30.2	"
Paopao	467	22.9	"
Bora Bora (1954)	230	24.7	"
Raiatea (1956)	657	20.5	"
Maiao (1949)	166	27.7	"
Huahine (1956)	304	25.0	"
Tahaa (1956)	342	27.5	"
Maupiti (1956)	514	26.6	"

The average microfilarial density in 20 cmm. of blood per positive also shows a rise with increasing age (Table 22). Microfilarial density *is high even in young children.* In children under 5 years of age, average microfilarial density is 24.8, and in children aged 5 to 9 years, 41.5. In the age group 10 to 19 years, it is 58.3, and in the later age groups, between 83 and 103.

TABLE 22

Microfilaria rates and average microfilarial density (20 cmm.) per positive for the different age groups of the rural districts of Tahiti based on studies carried out during 1949 (after Bambridge 1960).

Age group	Number examined	Number positive	Microfilaria rate	Total number of micro-filariae	Average microfilarial density in 20 cmm. per positive
0 - 4	859	61	7.1	1,512	24.8
5 - 9	1,714	246	14.4	10,204	41.5
10 - 19	3,051	763	25.0	44,515	58.3
20 - 29	2,162	785	36.3	65,111	82.9
30 - 39	1,626	666	41.0	68,635	103.1
40 - 49	1,246	539	43.3	47,733	88.6
50 plus	1,270	537	42.3	48,469	90.3

Subsequent to intensive mass treatment of the populations of the different islands with diethylcarbamazine during 1953 to 1958, the microfilaria rate dropped from 30.9 to 6.0 per cent in Tahiti, from 24.2 to 4.5 per cent in Papetoai (Moorea), from 27.1 to 7.6 per cent in Moorea (excluding Papetoai), from 27.7 to 2.6 per cent in Maiao, from 20.5 to 1.6 per cent in Raiatea, from 27.5 to 3.0 per cent in Tahaa, from 24.7 to 3.4 per cent in Bora Bora, from 25.0 to 3.3 per cent in Huahine, and from 26.6 to 2.2 per cent in Maupiti (Laigret 1959).

A high incidence of filarial disease has been known to be prevalent in the Society Islands since very early times. Bennett (1831) stated that elephantiasis was extensively prevalent in Tahiti and that hydrocele was very common. Lesson (1839) observed that crural elephantiasis was very common among the people of Tahiti and that even young children were sometimes affected with the disease; hydrocele and elephantiasis of the scrotum were stated to be common among males. Melville during 1842-43 observed many cases of elephantiasis among Tahitians, and mentioned that the disease has been in existence since remote times (Melville 1951).

According to Bennett (1840), elephantiasis was common among both natives and Europeans on Raiatea Island. Hercouet (1880) stated that the incidence of elephantiasis was very high on all the three islands, Tahiti, Moorea and Huahine. Gros (1892) mentioned that 5 per cent of the population of Bora Bora and Huahine were affected with elephantiasis. Tribondeau (1900) remarked on the extremely high prevalence of elephantiasis in Raiatea, Huahine and Moorea; it was mentioned that in the districts of Afareaitu and Haapiti on Moorea, about 50 per cent of the population were affected with the disease. Dubruel (1909) reported that 12 per cent of the total population of Huahine had elephantiasis, and 8 per cent of that of Moorea. The incidence of the disease was found to vary in different areas. The districts of Afareaitu and Papatoai on Moorea showed a higher incidence of the disease than other districts; on Tahiti, the districts of Papara, Tautira and Arue were affected to a greater extent than others. Villaret (1938) observed that the villages on the leeward side of Tahiti showed a higher incidence of elephantiasis than those on the windward side.

Gross elephantoid conditions were of very common occurrence in the Society Islands during the last century and the early part of the present century. Melville stated that in some of the cases of elephantiasis that he saw during 1842-43, the affected leg was as thick as the body trunk. Clavel (1884) mentioned of a case of elephantiasis of the scrotum from the Society Islands, in which the tumour was so heavy (over 35 kg. in weight) that the man's legs could not support it. Huguenin (1902) stated that the elephantoid leg may reach the size of a 225-litre barrel, and that the elephantoid scrotum may be so large and so heavy that the man was incapable of moving about by himself. Kermorgant (1908) also mentioned that in the Society Islands elephantiasis of the scrotum may often attain an enormous size.

Recent data on the incidence of elephantiasis in the Society Islands are furnished in Table 23.

TABLE 23

Island	Number examined	Elephantiasis rate	Authority
Tahiti (15 districts)	3,390	7.0	March et al. 1960
Tahiti	8,537	3.9	Beye et al. 1953
Moorea	-	5.2	Kerrest 1954
Bora Bora	-	1.5	Villaret 1938
Maiao	184	2.7	Report, Inst. Med. Res., Papeete, 1949
Maupiti	-	1.0	Kessel 1957

It would appear that there has been during recent times a regression in the incidence as well as in the severity of filarial disease in the Society Islands. *The gross manifestations* of filarial disease noted by many of the earlier workers are comparatively rare at the present time. The incidence of elephantiasis is now much lower than what it was previously. Villaret (1938) observed only a few cases of elephantiasis on Bora Bora Island, an incidence of approximately 1.5 per cent of the total population. In Moorea, formerly recognized to be a hotbed of elephantiasis, Villaret noted a marked regression in the incidence of the disease since the introduction of piped water supply to the villages. For instance, in the villages of Afareaitu and Papatoai which were severely affected with elephantiasis (Dubruel 1909), Villaret reported that there were very few new cases of elephantiasis since the provision of piped water supply. This was cited by Villaret as supporting the view that elephantiasis may be due to drinking contaminated water, and that the provision of a protected water supply had reduced the incidence of the disease in areas where the disease was formerly rife. A more plausible explanation of this observation seems to be that the provision of piped water supply has eliminated the barrels and other domestic containers for storing rain-water, and thereby reduced vector density in the vicinity of habitations and the intensity of transmission of filarial infection.

Aedes polynesiensis is the confirmed vector of W. bancrofti in the Society Islands. Galliard et al. (1949) reported that 50 per cent of A. polynesiensis from Tahiti showed natural infection with larvae of W. bancrofti. Beye et al. (1952) found that 6.7 per cent of 445 specimens of A. polynesiensis examined from Tahiti carried full-grown larvae of W. bancrofti, and 3.4 per cent of 88 A. polynesiensis from Maiao. During the period prior to the mass chemotherapy scheme, high rates of natural infection ranging from 6 to 21 per cent were recorded in A. polynesiensis from different islands of the Society group, as shown in Table 24.

TABLE 24

Natural infection rates in Aedes polynesiensis during the period prior to mass chemotherapy

Area	Period of observation	Number examined	Infection rate	Authority
Tahiti	1950-52	2,390	9.7	Rosen 1955
Maiao	1949	88	10.2	Beye et al. 1953
Moorea	1954	2,290	5.8	Laigret 1959
Raiatea	1956	732	11.2	"
Tahaa	1956	150	12.7	"
Bora Bora	1956	103	16.5	"
Huahine	1956	284	6.0	"
Maupiti	1956	155	21.3	

Subsequent to the mass chemotherapy campaign the infection rate in the vector mosquito dropped to 0.7 - 2.8 per cent in the different areas (Laigret 1959).

The breeding sites of A. polynesiensis are rain-water barrels, coconut shells, rat-damaged coconuts, tin-cans, tree-holes and crab-holes. Nearly all the inhabited areas on Tahiti and Moorea, and the majority of the villages on the Leeward Islands have, during the past 50 years, been provided with piped water supply. In such areas, domestic containers for storing rain-water have been almost completely eliminated. This type of breeding site is however of importance as a source of Aedes breeding in a few of the areas where there is no piped water supply.

Of the other types of breeding sites, by far the most prolific source of A. polynesiensis is the rat-damaged coconut. Rosen (1954) observed that "the rat-opened coconut is the most important breeding site of A. polynesiensis in the Society Islands". Edgar and Bambridge (1951) say that of the different types of breeding sites of this mosquito, the rat-damaged coconut is the most favourable; because of its narrow opening rain-water collecting in the rat-damaged coconut is protected from evaporation and held for a much longer period than in the open type containers; the darkness and humidity within the nut are favourable for the rapid development of the larval stages and for sheltering the adult mosquitoes that have emerged. In the Society Islands the coconut palms are heavily infested by rats which, according to Edgar and Bambridge (1951), are responsible for the loss of 28 per cent of the total coconut crop; other authorities estimate the damage at 30 to 60 per cent. Bonnett and Chapman (1958) say: "Since the coconut is the most important economic product of Tahiti and the coconut tree is planted extensively along the coastal belt of the island where the majority of the human population lives, the rat-eaten coconut is a problem of great magnitude". In the other islands of the Society group also, the villages are located on the coastal belt which is closely planted with coconut palms. The profusion of rat-damaged coconuts in these areas is responsible for the high vector density prevailing in the villages. The proximity of these breeding sites to habitations favours intensive transmission of filarial infection. In the Society Islands, prevention of damage to coconuts by rats is therefore of great importance in the control of filarial disease.

During the past seven years, the rat-damaged coconut has been very largely eliminated as a result of a scheme for the banding of coconut trees against damage by rats. This scheme, which has been financed by the FIDES (Fonds Intercolonial pour le Développement Economique et Social), was put into operation in 1956 as an economic measure for the protection of the coconut crop against rat damage. The banding of coconut palms on the islands of Tahiti, Moorea, Raiatea and Tahaa has already been completed, and in the other islands of the Society group, namely Bora Bora, Huahine and Maupiti, this work is nearing completion; it is expected that very soon all the coconut trees on each of the inhabited islands of the Society group would be effectively banded against rats. Although the primary object of this scheme is economic, the collateral benefit is the elimination of the rat-damaged coconut, an important source of Aedes breeding.

Consequent on the elimination of domestic rain-water containers in the majority of the inhabited areas as a result of the provision of piped water supply, and the elimination of the rat-damaged coconut through the banding of coconut trees, the only important sources of Aedes breeding existing at the present time in the village areas are litter such as coconut shells and tin-cans. It is a common practice for the people to dump such litter in bush near habitations.

Several improvements effected during recent years in the Society Islands have served to reduce filarial endemicity; firstly the provision of piped water supply; secondly the extensive banding of coconut trees against rat damage; and thirdly the mass treatment of the population with diethylcarbamazine.

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(12) Austral Islands

Austral Islands situated between latitudes 22° and 28° S., and between longitudes 145° and 155° W., comprise a chain of 7 small islands extending over a 800-mile stretch of ocean. The five inhabited islands of the group, Rimatara, Rurutu, Tubuai, Raivavae and Rapa, are high islands of volcanic origin, rising to heights of 300 to 2000 feet above sea level. The total land area is 63 square miles and the total population about 4,000. Tubuai, Raivavae and Rurutu have populations ranging between 900 and 1,300; Rimatara has a population of 650, and Rapa on the extreme south has about 260. The villages are located on flat areas along the coast. On many of the islands the number of coconut trees is not large, and copra making is not an important industry. The main villages on these islands have piped water supply (Massal 1963).

The Australs have a temperate-oceanic climate; the seasons are well-marked. Cool weather persists from May to September, and warm weather from November to March. It is never too warm or too cold. On Rapa Island (latitude 28° S.), temperature is seldom higher than 76° F., or less than 58° F.

Non-periodic W. bancrofti infection is known to be endemic in 4 of the 5 inhabited islands of the Australs, namely Rimatara, Rurutu, Tubuai and Raivavae; in regard to Rapa, the southernmost island of the group, we have no information. Villaret (1938) stated that only a few microfilaria carriers were found in the Australs and that they were persons that had come from the leeward group of the Society Islands. Beye et al. (1953) recorded a microfilaria rate of 19.1 per cent in Tubuai (235 persons examined). According to Kerrest (1954), the microfilaria rates are: Tubuai 25.8 per cent (62 examined), Rurutu 33.3 per cent (45 examined), and Raivavae 30.1 per cent (289 examined).

During 1961-1962 a detailed investigation covering nearly the entire populations of the four islands, Rimatara, Rurutu, Tubuai and Raivavae, was carried out by the Institut de Recherches Médicales de la Polynésie Française. *The writer is greatly indebted to Dr. E. Massal, Director of that Institute* for permission to quote from the unpublished reports on the filariasis surveys conducted in the Austral Islands. A summary of the findings on the incidence of filarial infection in these islands is furnished in Table 25.

TABLE 25

Microfilaria rates and microfilarial density in positives of four islands of the Australs (based on the reports of the Institute for Medical Research in French Polynesia).

(a) Island	(b) Number examined	(c) Number positive for micro-filaria	(d) Micro-filaria rate	(e) Average micro-filarial density per positive	(f) Number with low micro-filarial density (1 to 10 in 20 cmm)	(g) Percentage of low microfilaria counts (f) to total positives (c)
Rimatara	607	67	11.1	9.5	51	76.1
Rurutu	1281	199	15.5	26.5	100	50.3
Tubuai	927	82	8.8	16.9	60	73.2
Raivavae	901	199	22.8	17.2	138	69.3

Microfilaria rates (all ages) are low in Rimatara and Tubuai (11.1 and 8.8 per cent respectively), and higher in Rurutu and Raivavae (15.5 and 22.8 per cent respectively). The general intensity of infection in the microfilaria carriers is low. The average microfilaria count in 20 cmm. of blood, per positive ranges from 9.5 to 26.5. In the vast majority of the positives, microfilarial density is very low, 10 microfilariae or less in 20 cmm. of blood. Taking all the four islands together, 63.8 per cent of the total positives showed counts of 1 to 10 microfilariae in 20 cmm.

The incidence of filarial infection in the different age groups for the four islands taken together are presented in Table 26. Filarial infection is not uncommon in very young children; 4.4 per cent of children under 5 years of age, and 3.6 per cent of children aged 5 to 14, were positive for microfilaria in peripheral blood. In the next age group, 15 to 24 years, the microfilaria rate shows an abrupt rise to 18.8 per cent; in the later age groups, it is about 26 per cent.

TABLE 26

Microfilaria rates in different age groups for four islands of the Australs (from reports of filariasis surveys carried out by the Institute for Medical Research in French Polynesia)

Age group (years)	Under 5	5 to 14	15 to 24	25 to 44	Over 44
Number examined	477	1158	760	828	493
Microfilaria rate per cent	4.4	3.6	18.8	25.5	26.4

A noteworthy feature of the Austral Islands is the extreme rarity of endemic cases of filarial disease. Gros (1892) reported that no cases of elephantiasis were present on Tubuai Island. Villeret stated that filarial disease was uncommon in the Australs. He mentioned that no cases of elephantiasis were seen on Tubuai and Rapa, and that three cases were reported from Raivavae in 1933; it is not known whether these cases were indigenous or imported ones. Kerrest (1954) recorded a solitary case of elephantiasis on Raivavae Island, which may possibly be an imported case. He observed that although filarial infection is prevalent in the Austral Islands, clinical filariasis is practically non-existant. To quote: "L'infestation semble fréquente dans ces îles (Australes) mais il est particulièment remarquable de constater que les manifestations cliniques sont tout à fait exceptionnelles pour ne pas dire inexistantes".

The reports of the Institut de Recherches Médicales de la Polynésie Française (1961a & b, 1962a & b) which are based on a detailed examination and questioning of almost the entire populations of the four islands surveyed, stated that endemic filarial disease, acute or chronic, was extremely rare if not totally absent. Cases of elephantiasis found on some of the islands were among immigrants from the Society Islands, and on enquiry it was ascertained that these persons had developed elephantiasis in their original homes prior to their arrival in the Austral Islands.

Aedes polynesiensis is prevalent in the Austral Islands and is presumably the vector of _W. bancrofti_ here. The density of prevalence of this mosquito is very low, and facilities for its breeding are poor. The main villages are provided with piped water supply, and many of the other villages have communal cisterns for rain-water (Massal 1963). Several of the habitations have containers for storing water and these appear to be the main breeding sites of _A. polynesiensis_ in the inhabited areas. The number of such containers is however small. Unlike other Polynesian islands, coconut shells do not constitute an important source of _Aedes_ breeding. The number of coconut trees on the inhabited islands is small, and copra making is not an important industry.

The presence of microfilaraemia in a significant proportion of the population, and even in young children, shows that transmission of filarial infection occurs in the villages of the Australs. Transmission of the infection, however, does not appear to be intensive, judged from the low grade microfilaraemia and the absence of filarial disease in the population. Villaret (1938) expressed the view that the determinant factor responsible for the absence of filarial disease in the Austral Islands was the temperate climate. The low grade microfilaraemia in the carriers and the absence of endemic filarial disease may be attributed to the two factors unfavourable for intensive transmission, namely the temperate climate and the low vector density in the inhabited areas.

In recapitulation, endemic filarial infection has a wide distribution in the Austral Islands. The microfilaria rates for the different islands range between 9 and 23 per cent. The infections are mostly of a very low grade; high microfilaria counts are exceptional. In the vast majority of the positives, the microfilaria counts were 10 or less in 20 cmm. of blood. Filarial disease is practically non-existent in the Australs. The absence of endemic filarial disease in this group appears to be due to local conditions being unfavourable for intensive transmission of filarial infection, namely the temperate climate and the low vector density in the inhabited areas.

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(13) Makatea

Makatea Island (latitude 16° S., and longitude 148° W.) is situated about 120 miles northeast of Tahiti. Geographically, Makatea forms part of the Tuamotu Archipelago, but as it differs from the rest of the islands of that group in its physiological features and in the character of its population, it is here treated separately. Makatea is a raised coral island in the form of a hump, rising to a height of 220 feet above sea level, and covered with a thick crust of phosphatic rock. It has an area of 10 square miles, and a population

of about 2,300, consisting mostly of able-bodied men (and their families) engaged on working the phosphate deposits on the island. The habitations are concentrated in two settlements, Moumu at the middle of the bay on the north coast, and Vaitepaua at the centre of the island where most of the phosphate workers live. The rest of the island is practically uninhabited.

Makatea has practically no permanent population indigenous to that island. Its population is made up largely of immigrant labour from the Society, Cook and Tuamotu Islands, who come in for short terms and return to their homes thereafter. There is a regular weekly schooner service between Tahiti and Makatea. The schooner, which is always very crowded, brings in large numbers of labourers to Makatea every week, and takes back about an equal number. The population of Makatea is subject to constant change.

No information is available on the incidence of filarial disease in Makatea. Beye et al. (1953) examined 276 persons in Makatea found 41.6 per cent positive for microfilaria. As the population of Makatea consists of imported labour from the neighbouring islands, it is not possible to determine whether the infections noted in Makatea are autochthonous or imported.

Aedes polynesiensis, the vector of W. bancrofti in other parts of Polynesia, occurs in Makatea. Rosen (1955) recorded a natural rate of 9.7 per cent among 2,390 specimens of A. polynesiensis collected from Tahiti and Makatea taken together. But separate data for Makatea are not available.

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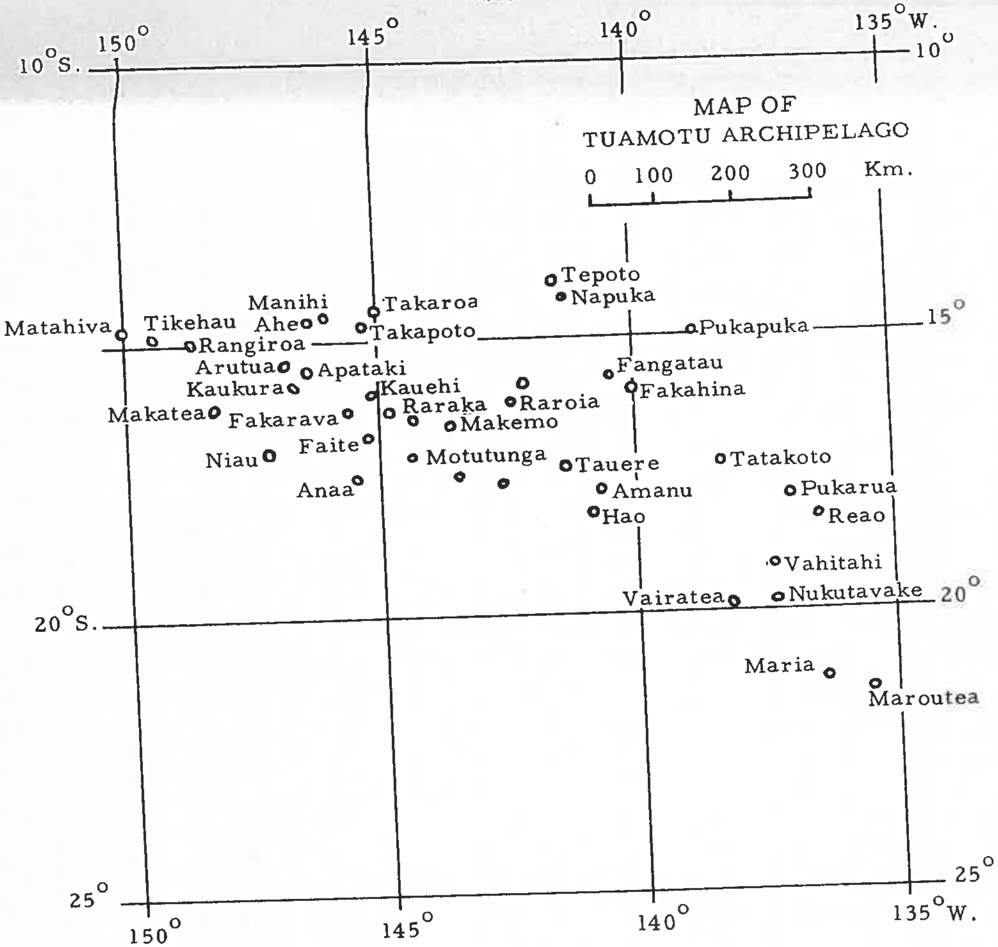
(14) Tuamotu Archipelago

The Tuamotu Archipelago comprises 78 coral islands scattered over a vast expanse of the ocean to the east of the Society Islands. The group extends from Matahiva on the northwest to Maroutea on the southeast (Map 13), and lies between latitudes 14° and 22° S., and between longitudes 149° and 135° W. Each of the islands of the group is of typical atoll structure consisting of a more or less complete ring of numerous, small, narrow, islets encircling a deep and spacious lagoon. Some of the atolls are of considerable size, as for example Fakarava, Rangiroa and Hao, each with a circuit of about 100 miles. The lagoon of Fakarava is 40 miles long and 15 miles in width; that of Rangiroa is 44 miles by 14; several others measure 15 to 20 miles in length and 8 to 15 miles in width. The total land area of the Tuamotu Archipelago is however small, about 300 square miles.

In the major part of the Tuamotu group, the climate is tropical-oceanic. Temperature and atmospheric humidity are high. There is no marked seasonal variation in temperature; a pronounced winter is lacking. Mean monthly temperatures range between 76° and 81° F. Being low islands, they do not derive much rainfall from the prevailing trade winds, and during some years,



MAP 13. Tuamotu Archipelago

rainfall is very low. Annual rainfall is about 48 inches on the average. There are two main seasons, - a warm season lasting approximately from November to April when most of the rainfall occurs, and a comparatively cooler and relatively dry season from May to October.

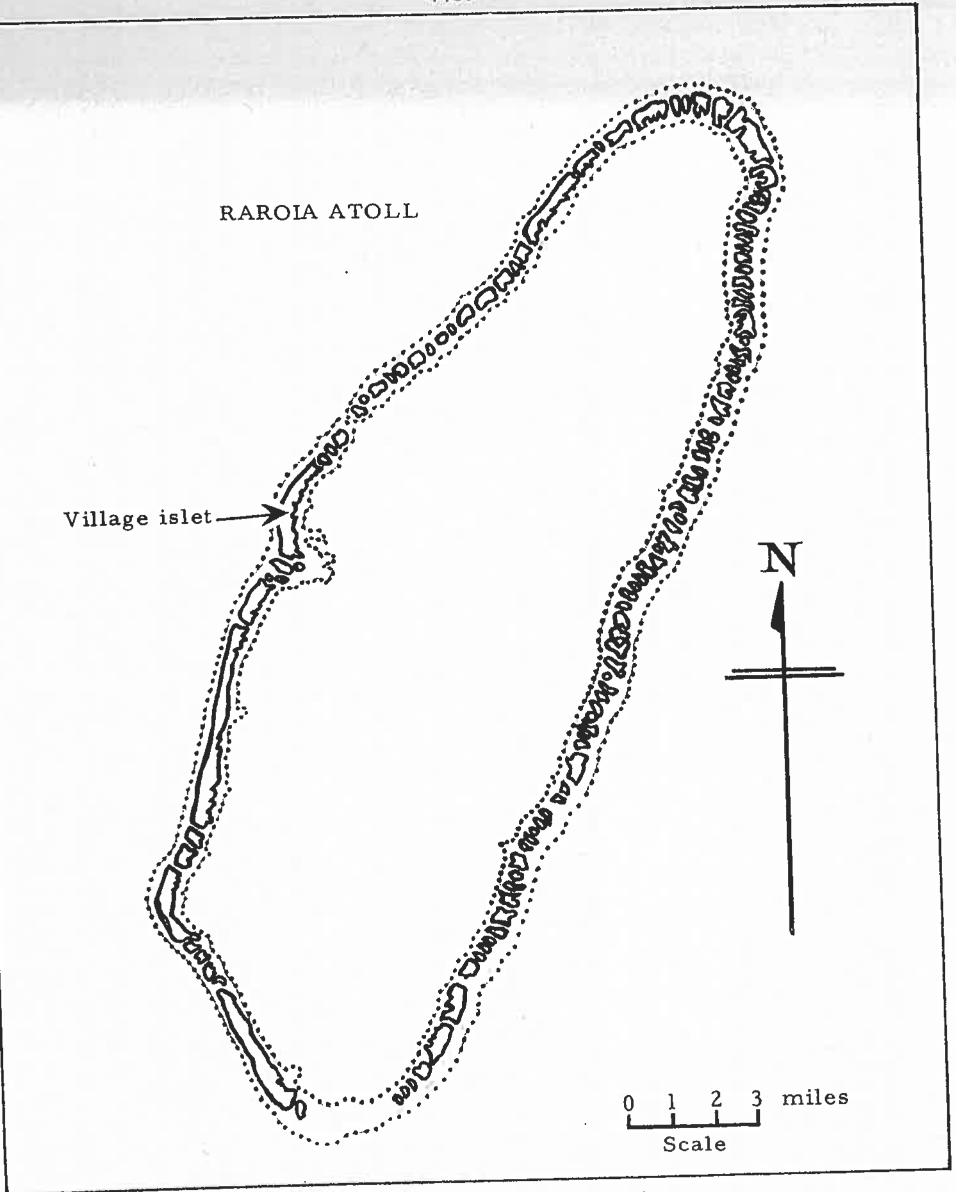
Of the 78 atolls comprising the group, only 35 are permanently inhabited. The total population is 7,500. A few of the atolls have populations of more than 300, as for example Rangiroa (700) and Anaa (400); most of the others have populations less than 250, and some with not more than 100.

Of the numerous islets comprising the atoll, only one is inhabited, and this is called the village islet. During pre-European times there were small settlements on several of the habitable islets of each atoll. During 1870 to 1880 a change in the settlement plan was initiated. Since then, the settlement has been restricted to a single islet on each of the atolls, except in a few like Fakarava and Rangiroa which have two such settlements. There are no permanent habitations on any of the other islets, all of which are reserved as plantations and are visited only for the purpose of collecting copra and other produce. The people do not spend more time on these islets than is strictly necessary for copra collection.

Raroia (Map 14) is a typical example of the atolls of the Tuamotus. Raroi is of considerable size, about 30 miles long and 9 miles wide, and consists of a ring of about 280 islets surrounding a large lagoon. The total population of Raroia is about 130, and all the people live on a single islet, Gurumaova, in the western part of the atoll. The other islets are not inhabited.

On the atolls of the Tuamotu group, there is great scarcity of fresh water. There are no streams or springs, and few surface collections of water. The soil being porous, rain-water quickly disappears into the soil. Subsoil water is brackish or even saline. The only source of fresh water is collected rain-water. On many of the village islets, the Administration have erected large concrete cisterns of the modern type for storing rain-water for the use of the people. On several others, the local people have constructed communal cisterns near the village community centres.

The village islet is small, compactly occupied with habitations, and kept in a tidy condition and free from bush and litter. As the villages are provided with cisterns for rain-water, the individual householder does not ordinarily keep barrels and other receptacles for storing rain-water. Opportunities for Aedes breeding are few and the village islets are fairly free from mosquitoes. On the uninhabited plantation islets, on the other hand, mosquito density is very high. The bush in the plantations is rarely cleared, and the ground is littered with enormous numbers of rat-damaged coconuts, a prolific breeding site for Aedes polynesiensis. Rats cause heavy damage to the coconut crop in the Tuamotu Islands. Danielsson (1956), discussing conditions on Raroia atoll, says: "How many nuts are eaten by the rats is of course impossible to compute with exactness. Judging from the number of pierced nuts found on the ground, the natives estimate that



MAP 14. Raroia atoll (Tuamotu)

the rats eat between one third to one half of the crop". On Fakarava atoll, according to Dumbleton (1955), 50 per cent of the total coconut crop and, in some areas, over 75 per cent are destroyed by rats. Similar conditions prevail on the other atolls of the Tuamotus. The occurrence of large numbers of rat-damaged coconuts on the plantation islets accounts for the high prevalence of A. polynesiensis on these islets.

As will be seen later, the habits of the people of Tuamotu have a large bearing on the epidemiology of filariasis, and it would be of interest to bring out some of the points of importance. For the collection of copra from the plantation islets, the people of Tuamotu follow a communal system of farming. The following description by Danielsson (1956) of Raroia would apply for the other atolls of Tuamotu as well.

"For the purpose of making copra the atoll is divided into several sectors, which are visited in turn by all land owners simultaneously, according to a rotation system previously agreed upon. A certain sector is declared open for copra work for a well defined period by the Chief after close consultation with the Village Council (and frequently the whole population). The owners who have land in this sector - and usually all have at least one parcel - sail over from the village and establish themselves somewhere in the sector until the work is done, whereafter they return to the village and await the opening of the next sector. The round of all sectors is usually made in eight months. With the scattered distribution of land holdings and the concentration of the whole population in one village the islanders have to make long canoe voyages in order to work the copra. All these trips are made in sailing canoes with out-riggers or in small boats, and as the wind is fairly strong and the surface of the lagoon rather rough for such small craft, the voyages to and from copra sectors are far from comfortable. If possible, most of the Raroians prefer to band together when working in the copra sectors. No good fresh water wells exist anywhere, and the most serious inconvenience of life in the copra sectors is, according to the islanders themselves, the inability over extended periods to wash in fresh water. Most of the sectors are infested with mosquitoes. The prevalent attitude towards work in the sectors is that it is trying and uncomfortable, and everybody always expresses great satisfaction upon return to the permanent village".

The copra collecting parties consist mostly of able-bodied persons between the ages of 15 and 44, and generally more of men than of women. Observations made in Raroia by Danielsson (1956) showed that people of this age group spend on the average 12.5 days each month on the plantation islets, and the rest of the time in the village. Children and old people stay mostly in the village.

Although non-periodic W. bancrofti infection was known to be endemic in the Tuamotu Archipelago, we did not have, until very recently, much information on the distribution and incidence of filarial infection in this group. Thanks to the Institute of Medical Research in French Polynesia for carrying out a very detailed filariasis survey in this group, we now possess reliable data in respect to 30 of the 35 inhabited islands of the Tuamotus. During these investigations which were carried out during 1959 to 1963, nearly 4,500 persons of all ages, representing about 90 per cent of the total population of the 30 islands, were examined. The findings are presented in Table 27. The writer is deeply indebted to Dr. E. Massal, Director of the Institute of Medical Research in French Polynesia, and to Mr. B. Bambridge, for permission to reproduce the data.

TABLE 27

Microfilaria rates and average microfilaria count per positive of 30 islands of Tuamotu Archipelago (Islands Nos. 1 to 4 after Bambridge 1959, and Nos. 5 to 30 after Massal 1963).

Island	Number examined	Number positive for micro-filaria	Micro-filaria rate	Average microfilaria count (20 cmm. of blood) per positive
1. Faaite	123	6	4.9	12.0
2. Raraka	36	1	2.8	48.0
3. Katiu	73	1	1.4	9.0
4. Kauehi	106	18	17.0	49.8
5. Apataki	123	22	17.9	46.1
6. Takatopo	173	12	6.9	10.3
7. Matahiva	147	18	12.2	13.2
8. Tikehau	231	25	10.8	11.4
9. Arutua	146	19	13.0	26.1
10. Takaroa	189	11	5.8	7.0
11. Ahe	150	11	7.3	5.4
12. Manihi	157	8	5.1	10.5
13. Fakahina	107	4	3.7	5.3
14. Fangatau	119	16	13.4	23.8
15. Pukapuka	119	3	2.5	13.0
16. Raroia	117	5	4.3	15.8
17. Napuka	193	0	0	0
18. Anaa-Fuuhora	265	11	4.2	5.4
19. Makemo	155	6	3.9	8.3
20. Kaukura	149	15	10.1	29.4
21. Fakarava	204	13	6.4	14.0
22. Niau	193	17	8.8	14.5
23. Tepoto	53	0	0	0
24. Tatakoto	182	5	2.7	4.2
25. Vahi-Tahi	107	0	0	0
26. Nukutavake	119	0	0	0
27. Hao	165	3	1.8	9.7
28. Vairaatea	104	1	1.0	1.0
29. Pukarua	212	2	0.9	39.5
30. Reao	272	7	2.6	10.4
Total	4489	260	5.8	19.6

The incidence of filarial infection in Tuamotu is very low. The overall microfilaria rate for 30 islands of the group, based on the examination of 4,489 persons of all ages, is 5.8 per cent. In four islands, namely Napuka, Tepoto, Vahi-Tahi and Nukutavake, the microfilaria rate is zero; in 16 islands, the microfilaria rate ranges between 1 and 6 per cent; in 6, between 7 and 12 per cent; and in 4, between 13 and 18 per cent. The highest microfilaria rates recorded in Tuamotu are from Kauehi and Apataki (17.0 and 17.9 per cent respectively). These two islands also show high intensity of filarial infection (average microfilaria counts per positive of 49.8 and 46.1 respectively).

The intensity of filarial infection in microfilaria carriers from the Tuamotus is of a very low order. A high proportion of the positives showed extremely low microfilarial densities. Table 28 furnishes a classification, according to microfilarial densities, of the 234 positives from islands Nos. 5 to 30 in Table 27. In 48.3 per cent of the positives, microfilarial density was between 1 and 5 in 20 cmm. of blood; nearly two-thirds (65.4 per cent) of the total positives showed microfilaria counts of 10 or less. Only in 16.2 per cent of the microfilaria carriers was the density higher than 30 in 20 cmm.

TABLE 28

Classification of 234 positives from 26 islands of Tuamotu (after Massal 1963)

Microfilaria count in 20 cmm.	1 to 5	6 to 10	11 to 30	31 to 100	over 100
Number	113	40	43	30	8
Percentage	48.3	17.1	18.4	12.8	3.4

The average microfilaria count per positive for the entire group is 19.6 (Table 27). Of the 26 islands in which filarial infection was noted to be present, the average count per positive was between 1 and 10 in eleven islands, between 11 and 20 in eight islands, between 21 and 30 in three, and between 31 and 50 in four. Of the four islands of the last category, in two, namely Raraka and Pukarua, the average is based on only one and two positives respectively.

Broadly speaking, the average microfilaria count per positive for different islands varies directly as the microfilaria rate (Table 27). For four of these islands, namely Raraka, Katiu, Vairaatea and Pukarua, the average microfilaria counts are based on only one or two positive findings and are therefore not representative of a true average. If we exclude these four islands and consider the other 22 islands for which the average microfilaria counts are based on larger numbers of positives (3 or more), a high degree of positive correlation is demonstrable between the microfilaria rate and the average microfilaria count per positive; the coefficient of $\underline{r}$ being + 0.83.

Analysis of the data shows that the incidence of infection shows a progressive rise with increasing age. Table 29 presents the data for 26 islands of the Tuamotus (Nos. 5 to 30 of Table 27).

TABLE 29

Microfilaria rates in different age groups for 26 islands of Tuamotu (after Massal 1963).

Age group	Under 5	5 to 14	15 to 24	25 to 44	Over 44
Number examined	552	1094	756	1044	705
Number positive	6	7	48	94	79
Microfilaria rate	1.1	0.6	6.3	9.0	11.2

In the early age groups, filarial infection is infrequent; the microfilaria rate among 1646 children under 15 years of age is 0.9 per cent. As the majority of the children spend most of their time on the village islets, they are not exposed to infection to any appreciable extent. In the older age groups, the microfilaria rate increases progressively, from 6.3 per cent in the age group 15-24, to 11.2 per cent in persons above the age of 44.

Bambridge (1959) examined 827 persons from ten islands of the Tuamotus. Table 30 furnishes an age-var classification of Bambridge's findings.

The age grouping followed in Table 30 is different from that in Table 29; however, the progressive rise in the incidence of filarial infection with increase in age is clearly brought out. None of the 70 children under 5 years of age showed filarial infection. In the age groups 5-9 and 10-19, the microfilaria rates are low, 2.0 and 3.4 per cent respectively. In the later age groups, the microfilaria rate shows a steady rise from 9.7 per cent in the age group 20-29, to 24 per cent in the last age group (50 years and over). Bambridge's observations also show that the average microfilaria count per positive, like the microfilaria rate, shows a rise with increasing age, reaching its maximum in the last age group.

Filarial disease is rare in Tuamotu, and endemic cases of elephantiasis are virtually unknown. Gros (1892) stated that elephantiasis was very rare in the Tuamotu Islands; he mentioned that only one case had been known from the whole group. Villaret (1938), quoting the observations of Massal (1934), stated that elephantiasis was practically unknown in Tuamotu. Villaret believed that the absence of cases of elephantiasis may be due to

TABLE 30

Microfilaria rates and average microfilaria count (20 cmm. of blood) per positive in the different age groups of ten islands of Tuamotu investigated by Bambridge, 1959).

Age group	0-4	5-9	10-19	20-29	30-39	40-49	50 plus
Number examined	70	152	177	144	120	89	75
Number positive	0	3	6	14	17	18	18
Microfilaria rate	0.0	2.0	3.4	9.7	14.2	20.2	24.0
Total number microfilariae	0	7	67	157	193	606	689
Average microfilaria count per positive	0	2.3	11.2	11.2	11.4	33.7	38.3

the low rainfall and the dry conditions prevailing in these islands. Massal (1960) mentioned that endemic cases of elephantiasis are not known to occur in the Tuamotus, and that such of the cases as have been reported are imported cases from the Society Islands. Bambridge (1959) examined 827 persons from ten islands of this group, and failed to find even a single autochthonous case of elephantiasis; a solitary case seen by Bambridge on Niau Island was, on further enquiry, found to be an immigrant from Raiatea (Society Islands), who had developed elephantiasis prior to his arrival in Niau. Filarial disease is not a problem in the Tuamotu Archipelago, even though _W. bancrofti_ infection is endemic.

Although no investigations have been carried out in Tuamotu Islands to determine the local vector of _W. bancrofti_, there can be little doubt that _Aedes polynesiensis_ is the vector in this area. This mosquito has a wide distribution in Tuamotu and is the only species of the _Aedes scutellaris_ group present here.

The prevalence of _A. polynesiensis_ in Tuamotu varies from one area to another. The islands with low rainfall have a much lower incidence of this mosquito than the islands with heavier rainfall. Even within the same atoll, its prevalence is very variable. In the village islets, this mosquito is only very rarely seen, whereas in the plantation islets it often occurs in such large numbers as to constitute a pest. The rarity of _A. polynesiensis_ mosquitoes on the village islets is due to lack of facilities for this mosquito to breed. Most of the villages have large rain-water cisterns of the modern type for communal use, and the people do not have to store water in domestic receptacles. There is little of litter on the village islets. Copra is prepared only on the plantation islets; the opened coconut shells are left in the plantations and only the copra is brought over to the village islet. Any coconut husk and coconut shells available on the village islet are used up for fuel. The villages are generally maintained in a tidy condition and there are few opportunities for Aedes to breed. Because of the extremely low vector density on the village islets, transmission of filarial infection is not feasible.

On the plantation islets, on the other hand, a high density of A. polynesiensis prevails everywhere. The profusion of favourable breeding sites for this mosquito, chiefly the rat-damaged coconut, accounts for the high density of this mosquito in the plantations. When a produce collecting party camps in a plantation, the people are exposed to bites by large numbers of A. polynesiensis, and as a result of proportion of the mosquitoes present there would get infected with larvae of W. bancrofti derived from microfilaria carriers that may be present in the party. As the collecting party does not camp on the same plantation site for longer than a week or ten days, and as it ordinarily moves on to a new site within the period required for the filarial parasite to reach the infective stage in the mosquito host, transmission of the infection is not likely to occur. When the people return to the village islet, they live in an environment which is practically free from exposure to infection. Any one area visited for copra collection is not likely to be visited again for several months thereafter, because the different sectors are worked in rotation. It was mentioned earlier that it takes eight months for a complete rotation of all the copra sectors of Raroia atoll; for the other atolls, the time taken for a complete rotation of the sectors would vary according to the size of the atoll. In the long interval between two visits to the same plantation area, any infection that may have been acquired by the mosquitoes present in any one locality during a previous visit would have died out by the time the same area is visited again for copra collection.

Transmission of filarial infection would occur whenever a party stays in one spot on a plantation for a period long enough for the infection in the mosquito to reach the infective stage. This happens not infrequently and, as a result, endemic filarial infection is present in the populations of the majority of the atolls of Tuamotu. The normal routine of life of the Tuamotu people is such that they do not stay permanently, or even for any appreciable length of time in contact with the same vector population to facilitate intensive transmission necessary for hyperfilariation in man. In consequence, endemic filarial disease is practically non-existent in Tuamotu.

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(15) Gambier Islands

Gambier Islands (latitude 23° S., and longitude 135° W.) situated southeast of the Tuamotu Archipelago, consist of a cluster of very small, elevated islands of volcanic origin, enclosed within a barrier reef. Four islands are inhabited, namely Mangareva, Taravai, Akamaru and Aukena. Mangareva, the main island of the group, is 4 miles in length and about one mile in maximum width; the others are much smaller in size. The total population of the Gambiers is about 600. The vast majority of the people live on Mangareva; the other three inhabited islands have very small populations, about 70 on each.

Gambier Islands have an ocean-moderated temperate climate. Average annual rainfall is about 80 inches. There are no permanent streams on any of these islands. For their supplies of fresh water the people formerly collected and stored rainwater in barrels and domestic receptacles. During the past 50 years, communal cisterns of the modern type have been erected on the inhabited islands, and Rikitea, the principal settlement on Mangareva Island, has been provided with a piped water supply, tapping a perennial spring at the foot-hills.

Aedes polynesiensis occurs in the Gambier Islands and is presumably the local vector of non-periodic W. bancrofti.

During the later part of the last century, elephantiasis was reported to be prevalent in the Gambiers (Hirsch 1886, Gros 1892). More recent reports indicate that cases of elephantiasis are quite uncommon. Perrin (1932) noted only two cases of elephantiasis and two cases of chyluria among the total population of the Gambiers. Villaret (1938) stated that cases of elephantiasis were rare.

The rarity of cases of elephantiasis in the Gambiers at the present time is in striking contrast to the high incidence of the disease noted by observers of the last century. Villaret (1938) thought that the rarity of elephantiasis in the Gambiers was due to the temperate climate and to the drinking water being pure. During the past 50 years considerable improvement in environmental sanitation has been effected in the inhabited areas of the Gambiers, notably the construction of modern cisterns for storing rain-water on each of the inhabited islands, and the provision of piped water supply for Rikitea. The population of the Gambiers which was formerly scattered in many small hamlets, has now largely concentrated in Rikitea, a clean and tidy settlement in which the vast majority of the people live. There is justification for the presumption that the aggregation of the population in Rikitea and the provision of piped water supply to the inhabited areas have been responsible for the marked reduction noted in the incidence of filarial disease. Formerly the people kept many rain-water receptacles in each house, and these constituted perennial breeding sites for A. polynesiensis. The proximity of these breeding sites to habitations favoured intensive transmission of filarial infection. Since the provision of communal cisterns for rain-water in the villages and of piped water supply in Rikitea, the principal settlement, there is no longer any need for the householder to maintain receptacles for storing water. With the elimination of these breeding sites in the vicinity of habitations, intensive transmission of filarial infection seems no longer feasible. This is offered as a plausible explanation of the present rarity of cases of elephantiasis in the Gambier Islands.

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(16) Marquesas Islands

Marquesas Islands, situated about 750 miles northeast of Tahiti, lie between latitudes 8° and 11° S., and between longitudes 138° and 141° W. The group comprises ten fairly large mountainous islands of volcanic origin, of which six are inhabited. The total land area of the group is 492 square miles and the total population is about 4,000.

The Marquesas have a tropical-oceanic climate with little seasonal variation. Mean annual temperature is about 78° F. The difference between the mean temperature of the coldest month (August) and that of the hottest month (November) is only 4° F. Relative humidity is high practically all through the year, and seldom drops below 80 per cent. Rainfall is generally heavy. During wet years annual rainfall is well over 100 inches, but ordinarily it is about 60 inches.

The moutainous areas in the interior are not inhabited. The Marquesans live in small scattered hamlets on the narrow flat areas of the lower reaches of the valleys. On the larger islands, plenty of fresh water is available in these valleys. On the smaller islands there is often much scarcity of fresh water. Many of the streams, even in their lower reaches, are intermittent, drying up completely in times of drought, or continuing underground to the sea appearing only here and there as springs. For their supplies of fresh water, the people collect spring water or rain-water and store it in domestic containers. While formerly the population was scattered,

at the present time the population is largely concentrated in two main centres, Taiohae on Nukuhiva Island, and Atuona on Hiva-oa Island, which together carry more than three-fourths of the total population of the Marquesas.

Filarial disease is common in the Marquesas. Buxton (1928) mentioned that Miss Cheesman and Dr Crossland, members of the "St. George" Expedition of 1925, found cases of elephantiasis on each of the three islands that they visited, namely Hiva-oa, Nukuhiva and Fatuhiva. Rollin (1929) reported that in the Marquesas cases of elephantiasis were seen in every valley, and especially at Hapatoni on Tahuata Island. Villaret (1938) stated that elephantiasis was rife in all the islands of the Marquesas, and especially in the islands of the southern group. Benoit (1937) reported that 50 to 60 per cent of the populations of Hapatoni (Tahuata), Nahae (Hiva-oa), and Hakaui (Nukuhiva) suffered from elephantiasis; he also stated that 19 per cent of the total number of deaths in Hiva-oa were due to filariasis or its complications. Mumford and Adamson (1933) stated that elephantiasis was common in the Marquesas. Bambridge (1956) recorded an elephantiasis rate of 3 per cent in this group. Rosen (1954) observed: "On each of the six inhabited islands, at least 5 per cent of the total population had gross manifestations of elephantiasis. On each island there were individuals with elephantiasis who had never lived elsewhere. In addition, several Europeans who had never been exposed in other endemic areas of filariasis had also acquired elephantiasis in the Marquesas Islands".

Many of the reports of the later part of the last century stated that elephantiasis was rare or even totally absent in the Marquesas (Vinson 1858; Hercouet 1880; Clavel 1884; Gros 1892). This may give the impression that the Marquesas have, suddenly during the early decades of the present century, become a hotbed of elephantiasis. It may be pointed out that the views expressed in the reports of the last century were not based on any detailed study of the populations of these islands, but on impressions gathered from casual contact with able-bodied young men that came to the schooners during the very brief visits of these observers. Further, the period of these reports corresponded to a time when the population of the Marquesas was at its lowest level, about 1800 in all, having been decimated as a result of various factors such as depredations by black-birders, series of wars with the French (circa 1850), wave after wave of epidemic diseases, and frequent internecine and cannibal wars. The population of the Marquesas at the time of these observations consisted largely of young people, the majority of the older people having died during the epidemics of communicable diseases (Massal 1960). The unfriendly disposition of the Marquesas towards the French at that time was not favourable for any close contact with the people as a whole. Clavel (1884), however, noted several cases of elephantiasis among the Marquesans and stated that the condition was locally known as "He-he". The fact that elephantiasis had a local name for it in the Marquesas even as early as 1884 would indicate that the disease was by no means uncommon. These facts are brought out to show that elephantiasis has been prevalent in the Marquesas since early times.

Endemic W. bancrofti infection has a wide distribution in the Marquesas, and the microfilaria rates are often very high. Benoit (1932 & 1937) recorded microfilaria rates of 50 and 90 per cent from different areas of the southern islands of the Marquesas, probably based on the examination of small samples of adults. Rosen (1954) examined blood smears taken from 59 inhabitants of Fatuhiva Island and found 32.2 per cent of them positive for microfilaria. Bambridge (1956) recorded a microfilaria rate of 33.7 per cent in the Marquesas.

Although no studies have been made to determine the vector of W. bancrofti in the Marquesas, it may be presumed that Aedes polynesiensis is the vector here. This mosquito is abundant in all the inhabited areas of the Marquesas (Mumford & Adamson 1933, Rosen 1954).

During very recent years there has been an appreciable improvement in the condition of several of the inhabited areas in the Marquesas. The population is now largely concentrated in two main settlements of a quasi-urban character, namely Taiohae on Nukuhiva and Atuona on Hiva-oa, both of which are provided with piped water supply, schools and hospitals. The populations of these two centres together constitute nearly 80 per cent of the total population of the group. In these places, a regression in the incidence of filarial disease has been noted (Massal 1960), evidently brought about through reduction in the local vector density as a result of the concentration of population, provision of piped water supply, and fair sanitary supervision.

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(17) Pitcairn Island

Pitcairn Island (latitude 25° S., and longitude 130° W.) is the easternmost inhabited island of the South Pacific. It is a very small mountainous island of volcanic origin, rising to a height of 1000 feet, and with an area of 2 square miles. The total population is 150; all the people live in a single village, called Adamstown, on the north coast of the island. The climate of Pitcairn is equable. Mean temperature during winter is 65° F., and during summer, 82° F. There are no permanent streams on Pitcairn. The principal source of fresh water is collected rain-water. Each house has its own cistern, built of stone slabs cemented together, for storing rain-water using the corrugated iron roof of the house as catchment.

Neither filarial disease nor filarial infection is endemic in Pitcairn. Beye et al. (1953) examined blood samples taken from 54 Pitcairn Islanders for the presence of microfilaraemia with entirely negative results. Aedes polynesiensis, the vector of W. bancrofti in Polynesia, occurs in Pitcairn Island. The temperate climate and the low density of A. polynesiensis are the probable factors responsible for the absence of endemic filarial infection in Pitcairn Island.

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X. NEW CALEDONIAN ZONE: NEW CALEDONIA AND LOYALTY ISLANDS

New Caledonia and Loyalty Islands together constitute the New Caledonian zone. They lie between latitudes 20° and 23° S., and between longitudes 164° and 169° E. New Caledonia is a large mountainous island of volcanic origin, about 250 miles long and 30 miles in width, and with an area of about 6,200 square miles. It is traversed by two parallel ranges of mountains which rise to heights of about 5000 feet above sea level. Except for the narrow and discontinuous coastal strip, the entire island is hilly. Numerous streams arising in the mountains run short and torrential courses to the sea, broadening out at the mouths into tidal flats and mangrove swamps. The total population of New Caledonia is about 56,000, of which about 23,000 are concentrated in the town of Noumea. The country side is sparsely populated.

The Loyalty Islands (area 800 square miles) comprise a chain of three islands, Lifou, Mare and Ouvea, lying parallel to the east coast of New Caledonia and about 50 miles away. These islands are of limestone formation, with an undulating interior rising not higher than 300 feet above sea level. The total population of Loyalty Islands is about 14,000.

Of the 71,000 constituting the population of New Caledonia and the Loyalty Islands, only 37,000 are indigenes, and they are Melanesians.

The rest of the population is made up largely of people of European extraction.

Climate is subtropical. There is marked difference between the summer and winter temperatures. During summer, temperature may rise to a maximum of 94° F., and during winter it may drop to a minimum of 56° F. Mean temperature during the summer months is about 80° F., and during the winter months, 69° F. Mean relative humidity is not unduly high, and ranges between 68 and 81 per cent. Rainfall averages about 42 inches on the west coast of New Caledonia, and 78 inches on the east coast. In the Loyalty Islands, annual rainfall is about 65 inches on the average. Rainfall is seasonal; the major part of the precipitation occurs during summer.

Endemic filarial infection in the New Caledonian zone consists of the non-periodic race of *W. bancrofti*. Although situated very close to New Hebrides where periodic *W. bancrofti* is widely prevalent, this infection has not spread into the New Caledonian zone. The distance from Aneityum in New Hebrides, to Mare in Loyalty Islands, is only about 120 miles. *Anopheles farauti*, the vector of periodic *W. bancrofti*, is absent in New Caledonia and Loyalty Islands. The New Caledonian strain of non-periodic *W. bancrofti* is allied to the Polynesian strain and appears to have evolved from the latter introduced into this zone through immigrants from central Polynesia several centuries ago.

Studies on microfilarial density in peripheral blood carried out over a 24-hour period in six carriers from New Caledonia (Iyengar 1954a) showed the lack of microfilarial periodicity. The data are reproduced in Table 31.

TABLE 31

Microfilaria counts in 20 cmm. of peripheral blood in carriers from Mou village, New Caledonia, (averages of six cases studied, after Iyengar 1954a).

Hour	Microfilaria count
0900	37.3
1100	41.3
1300	58.2
1500	58.7
1700	52.2
1900	53.5
2100	42.7
2300	39.0
0100	31.8
0300	27.7
0500	39.3
0700	37.0
0900	48.7

The main foci of filarial infection in New Caledonia are (1) Balade, Pouebo, Touho, Mou and Ouasse on the east coast, and (2) Koumac, Gomen, Voh and Nepou on the west coast. In the Loyalty Islands, cases of filarial infection have been recorded from Lifou and Ouvea. The recorded microfilaria rates for these foci are furnished in Table 32.

TABLE 32

Microfilaria rates of the main endemic foci of filarial infection in New Caledonia and Loyalty Islands

Area	Number examined		Micro-filaria rate	Observer
New Caledonia				
(a) East Coast				
Ponerihouen				
Mou village	57	adults	49.1	Merlet 1950
"	86	all ages	37.2	Iyengar 1954a
"	-	-	42.0	Lacour & Rageau 1957
Touho	-	-	25.0	"
Pouebo	81	adults	59.3	Kerrest 1951
"	-	adult males	56.0	Merlet 1950
"	-	adult females	41.0	"
"	-	-	28.3	Lacour & Rageau 1957
Balade	-	-	13.0	"
Ouasse	-	-	25.0	"
(b) West Coast				
Koumac	24	adults	16.6	Kerrest 1951
"	-	-	4.0	Lacour & Rageau 1957
Gomen	13	adults	7.7	Kerrest 1951
"	-	-	1.4	Lacour & Rageau 1957
Voh: Gatope	45	all ages	22.2	Merlet 1950
"	-	-	16.3	Lacour & Rageau 1957
Voh: Oundjo	129	all ages	24.8	Merlet 1950
"	-	-	9.3	Lacour & Rageau 1957
Loyalty Islands				
Lifou	-	adults	3.0	Perry 1950
Ouvea	-	adults	11.0	"
Ouvea: Fayaoue	-	-	9.0	Lacour & Rageau 1957
Ouvea: St. Joseph	-	-	21.0	"

Endemic filarial infection is restricted in its distribution to foci along the coast. The interior areas are free from the infection. Merlet (1950) observed that in communities living even a few miles to the interior from a coastal focus, the infection was practically absent. Merlet recorded a microfilaria rate of 24.8 per cent in Oundjo situated close to a coastal swamp, whereas in a tribe living close to Oundjo but on an undulating area in the interior, only one person out of 100 examined proved to be positive for microfilaria. In Nassirah village, situated 4 miles to the interior from the coastal marshes of Bouloupari, although the vector mosquito, Aedes vigilax, occurs in fair numbers during certain seasons of the year, none of the local residents showed filarial infection (Iyengar 1954b); the two cases positive for microfilaria seen in Nassirah were imported cases from Wallis Island where filarial infection is highly endemic.

Although the distribution of W. bancrofti infection is coastal, not all coastal areas are endemic for filarial infection. Coastal villages not situated close to mangrove swamps have little or no filarial infection. In Tieti village near Poindimie, none of 100 persons examined showed filarial infection; Tieti, although situated right on the sea coast, has no mangrove swamps within a distance of several miles. In Embouchure village (Ponerihouen) situated close to the sea coast, but at a distance of a mile from mangrove swamps, the microfilaria rate was 1.5 per cent, whereas in the neighbouring villages of Ti and Mou which are situated close to the mangrove swamps the microfilaria rate was 37 per cent (Iyengar 1954a).

Merlet (1950) observed that in Oundjo (Voh), the incidence of filarial infection showed an increase with age, reaching 60 per cent in persons above the age of 40 years. Iyengar (1954a) noted a progressive increase with age both of the infection rate and of the average microfilarial density per positive (Table 33).

TABLE 33

Microfilaria rate and average microfilarial density in different age groups in Mou village (after Iyengar 1954a)

Age group	0-4	5-9	10-14	15-19	20-29	30-39	40-49	Over 50
Number examined	5	7	10	10	17	7	15	15
Microfilaria rate	0	0	20.0	30.0	47.1	57.1	46.7	53.3
Average microfilaria count (20 cmm.) per positive	0	0	4.0	5.4	10.6	16.0	34.1	28.3

In New Caledonia, the intensity of infection in the microfilaria carriers is of a low order. Lacour and Rageau (1957) determined the average microfilarial density (in 20 cmm. of blood) for 21 localities; in 18 of the 21 localities, the average microfilarial density ranged between 1 and 9, while in three others it was 11, 13, and 22 respectively. Even in Mou village with a microfilaria rate of 37.2 per cent (all ages), the average microfilarial density in 20 cmm. of blood per positive was only 20 (Iyengar 1954a).

The incidence of filarial disease in New Caledonia and Loyalty Islands is extremely low. Merlet (1950) noted the remarkable absence of clinical signs of filarial disease even in communities with high incidence of filarial infection. Merlet thought that this was due to climatic conditions being unfavourable for a high prevalence of filarial disease. Only a very small number of cases of elephantiasis are known from this area; they are: one case from Mou village (Merlet 1950, Iyengar 1954a), one from Gatope (Merlet 1950), three from Hienghene (Lacour & Rageau 1957), and two from Ouvea (Sanner quoting observations of American workers). Even manifestations of filarial disease like lymphadenitis, lymphangitis and hydrocele are of rare occurrence (Merlet 1950, Iyengar 1954a). New Caledonia and Loyalty Islands present the picture of an area with many endemic foci of W. bancrofti infection, but with little of filarial disease.

The vector of W. bancrofti in the New Caledonian zone is Aedes (Ochlerotatus) vigilax. The vectors of non-periodic W. bancrofti of the Polynesian zone, namely Aedes polynesiensis and allied species, are totally absent in this area. Likewise the vectors of periodic W. bancrofti of the Papuan zone, namely Anopheles farauti and allied species, are also absent.

The recorded natural infection rates in A. vigilax are: 5 per cent in Mou village (Iyengar 1954a), and 2.2 per cent for the areas investigated by Lacour and Rageau (1957). Under experimental conditions the New Caledonian strain of non-periodic W. bancrofti undergoes normal development in A. vigilax, reaching the infective stage in 12 to 14 days. Experimental infection rates recorded in A. vigilax with the New Caledonian strain of W. bancrofti are as follows: 57.1 per cent (Iyengar 1954a); 94.0 per cent (Iyengar & Menon 1956); 95.8 per cent (Backhouse & Woodhill 1956).

Of the other species of mosquitoes occurring in New Caledonia. two species namely Culex fatigans and Aedes (Finlaya) notoscriptus were found to be hospitable (under experimental conditions) to the New Caledonian strain of non-periodic W. bancrofti. In Culex fatigans the parasite developed normally and reached the infective stage in 13 days; the experimental infection rates recorded in this mosquito are 95.6 per cent (Iyengar & Menon 1956), and 95.2 per cent (Backhouse & Woodhill 1956). In experimentally infected Aedes notoscriptus, an infection rate of 72.2 per cent was recorded by Iyengar and Menon (1956), and infective stage larvae were seen in the head and labium of the mosquito on the 15th day after the infective feed. Although C. fatigans and A. notoscriptus are hospitable to W. bancrofti under experimental conditions, they do not appear to be of importance in the transmission of filarial infection in this zone. They were not found infected in nature, and neither of these two species is common in the areas with endemic filarial infection.

The following is an account of the bionomics of <u>Aedes vigilax</u> based on studies carried out in New Caledonia (Iyengar, unpublished observations). <u>Aedes vigilax</u> is a prolific breeder and breeds in stagnant, shallow pools of brackish or saline water well exposed to direct sunshine. It breeds only in stagnant water collections; even a feeble flow of water renders a breeding site unfavourable for this mosquito to breed, and it is absent in water collections even partially subject to tidal influence. Shallow pools are more favourable breeding sites than deeper pools; it was not found breeding in water collections with a depth of water greater than 18 inches. In New Caledonia, <u>A. vigilax</u> was not found to breed in fresh water collections. The salinity of the water in the breeding sites covered a fairly wide range, from 0.6 to 2.7 per cent chlorides. It is capable of breeding in water with a salinity higher than that of sea-water, but not in water in which the salinity has reached the saturation point. Optimum salinity for this mosquito to breed ranged between 1.0 and 2.6 per cent. In pools with a chloride content of less than 0.9 per cent, its breeding density was comparatively low; only infrequently was <u>A. vigilax</u> breeding observed in water collections with a chloride content of less than 0.5 per cent. Lowering of the salinity of the water in a ground pool, as for example after heavy rainfall, has the effect of rendering the breeding site unsuitable for this mosquito to breed.

Exposure of the brackish or saline water pool to direct sunshine is an essential factor for <u>A. vigilax</u> to breed. Pools that are shaded by overhanging vegetation are totally free from larvae of <u>A. vigilax</u>. In a series of stagnant pools of saline water in the bed of a small stream near its blocked mouth, <u>A. vigilax</u> was found to breed only in pools that were fully exposed to sunshine, while those that were shaded by mangrove vegetation were totally free from larvae even though other conditions like salinity and depth of water were the same in both sets of pools. Exposure of water to sunshine determines the availability of food for the larva. Brackish and saline pools exposed to sunshine are rich in algal plankton composed chiefly of certain diatoms, desmids and euglenids. These plankton organisms were recovered from the gut contents of larvae of <u>A. vigilax</u> collected from the breeding sites. In pools shaded by vegetation such plankton was practically absent, indicating that the occurrence of the algal plankton was directly related to exposure of the water to sunshine.

Clearing of mangrove vegetation and interference with tidal flow of water in salt marshes are important factors which favour intensive breeding of <u>A. vigilax</u>. The blocking of the mouth of a tidal stream with sand or shingle bars converts the terminal part of the stream into a prolific breeding site, if the water is exposed to sunshine. Pools left by high tides and not covered again till the next high tide comes in. are also favourite breeding sites.

Although <u>A. vigilax</u> breeds practically all through the year, it is subject to marked seasonal variation. Maximum breeding occurs during the summer months when temperature is high and rainfall is frequent. During summer, <u>A. vigilax</u> completes its larval development within as short a period as 10 days. Low temperature inhibits <u>A. vigilax</u> breeding and greatly prolongs the duration of its larval stages. During winter months when temperature is low and rainfall is scanty, <u>A. vigilax</u> breeding is at a low level.

In the New Caledonian zone, transmission of filarial infection is seasonal and largely restricted to the summer months when rainfall is frequent and temperature is high. During summer (December to March), mean temperature ranges between 78° and 81° F. This period is also the season of maximum breeding of <u>Aedes vigilax</u>. During the winter months (June to August) mean temperature is low (67° to 69° F), and rainfall is scanty. During this period the extent as well as the intensity of <u>A. vigilax</u> breeding is at a very low level.

<u>Aedes vigilax</u> is a diurnal mosquito which is active only during daytime; it is a vicious biter. It is an exophilous species and rests commonly in grass and low vegetation close to the damp soil, and only infrequently rests inside dwelling houses. <u>Aedes vigilax</u> is a strong flyer, capable of travelling long distances and is often found in large numbers even at distances of several miles from breeding sites. However, it is only the freshly emerged mosquito that is capable of travelling such long distances. Examination of mosquitoes caught at distances of a mile or more from breeding sites showed that they consisted entirely of nulliparous females that have not yet had a blood meal. Being unencumbered either by a blood meal or by developing ova, the newly emerged female has high buoyancy. Once she has had a blood meal, her buoyancy is greatly reduced and she is subsequently incapable of covering the long distances that she was capable of prior to the blood meal. Engorgement causes an immediate overloading; as the blood meal is being digested, the ovarioles in her ovaries develop simultaneously. As the ova reach maturity, the gravid female tends to move by stages towards a suitable breeding site for egg-laying. Even after she has oviposited and relieved herself of the load of matured eggs, she does not regain her original buoyancy, because yet another series of ovarian follicles is developing to maturation. While newly emerged, unfed, nulliparous females may often be seen at long distances from breeding sites, parous females stay very close to breeding sites and are incapable of travelling the distances that they were able to cover during their maiden flights.

From the point of view of transmission of filarial infection, the flight range of the parous female is the important consideration, and not the flight range of the nulliparous female, even though the latter may be of importance from the point of view of the dispersal of the species and causation of mosquito nuisance. Transmission of filarial infection is possible only when the distance between the vector breeding site and the village is less than the flight range of the parous female. This would explain the fact that although many areas in New Caledonia have a high prevalence of <u>A. vigilax</u> mosquitoes, endemic <u>W. bancrofti</u> infection is restricted to villages situated in the proximity of extensive vector breeding sites.

Under conditions of gonotropic concordance, which is the normality with mosquitoes in the tropics, a blood meal is followed by the maturation of ova and the necessity for the mosquito to visit the breeding site for oviposition. Taking the gonotropic cycle of <u>A. vigilax</u> as 3 to 4 days, the female mosquito would have to undertake at least three gonotrophic flights (from the village to the breeding site and back) during the period of 12 to 15 days nee for filarial infection acquired by the mosquito to reach the infective stage. The hazards of death and of scatter of the potentially infective mosquito each of these flights increase in proportion to the distance of the breeding site from the village. The closeness of the village to the vector breeding site is therefore of great importance in ensuring transmission of filarial infection. Infected A. vigilax mosquitoes were found only in those areas where the human habitations are close to vector breeding sites. In Mou village, infected mosquitoes were caught in larger numbers in that part of the village which is close to the breeding site, than at the farther end of the village. The occurrence of several broods of W. bancrofti larvae in some of the infected specimens showed that the mosquito had done several gonotrophic flights during the period of incubation of the parasite in the mosquito host.

The vector being a salt-marsh breeder, endemic filarial infection is restricted in its distribution to coastal foci. Villages situated even a mile to the interior are free from the infection, even though such villages have a high incidence of A. vigilax. Not all coastal villages however have endemic filarial infection. Coastal villages situated at distances of a mile or more from saline marshes are free. The known endemic foci in New Caledonia are coastal villages situated close to mangrove swamps. In these foci, the microfilaria rates vary considerably, from 1.4 to 37.2 per cent (taking all ages into consideration). The microfilaria rates of these foci seem to vary in direct relation to the proximity of the village to the breeding sites of the vector mosquito. Even in villages with high microfilaria rates, the incidence of filarial disease is extremely low, and cases of elephantiasis rare. The endemic foci appear to be sufficiently close to vector breeding sites for transmission of filarial infection to occur, but not close enough to ensure intensive transmission necessary for the establishment of hyperfilariation in the human host. The low grade infection found in the microfilaria carriers shows that facilities for intensive transmission in the endemic foci are poor.

In striking contrast to the extreme rarity of cases of filarial disease at the present time, cases of elephantiasis and of other manifestations of filarial disease were of very common occurrence during the 18th and 19th centuries. The earliest available report of the occurrence of elephantiasis in New Caledonia is that of Sir John Hayes, who spent a week in New Caledonia during June 1793; in his diary he noted that he saw several of the natives in the area around Gomen Bay (north-west coast of New Caledonia) affected with elephantiasis (Lee 1912, Carter 1946). We have several authentic reports on the occurrence of high incidence of elephantiasis among the coastal populations of New Caledonia and Loyalty Islands during the period following the annexation of the territory by the French in 1853. Vinson (1858) stated that elephantiasis arabum was frequently seen among the inhabitants of the coastal areas of New Caledonia, and that the parts affected were chiefly the leg and the scrotum. De Rochas (1860 & 1862) observed that elephantiasis, affecting mainly the leg and the scrotum, was of frequent occurrence in New Caledonia, and that the incidence of the disease was greater in the northern part of the island than in the southern part; he further stated that the population of the Loyalty Islands was affected with this disease to a much greater extent than that of New Caledonia. Bougarel (1870) published a photograph of a case of gross elephantiasis of the scrotum in a native of New Caledonia. Delas (1873) noted that elephantiasis of the leg was common in New

Caledonia, and that hydrocele was very common among adult males. Even Europeans were often found affected with these conditions. Vaysset (1874) recorded a case of elephantiasis in a European missionary. Several other observers of that period (Boyer 1878, Lombard 1880, Gunn 1883, and Brassac 1884) corroborated the observations of earlier workers on the high incidence of elephantiasis in New Caledonia and Loyalty Islands. Seguin (1891) stated that the tribes of Koumac, Gomen, Paqueque and Temala in New Caledonia, suffered from a high incidence of elephantiasis. Hirsch (1886) mentioned that the northern part of New Caledonia was "among the worst regions of the globe for elephantiasis".

The reports cited above show that elephantiasis and other manifestations of filarial disease were extremely common in this zone during the last century. At the present time, cases of filarial disease are extremely rare. This remarkable regression in the incidence of the disease was brought about as a result of the shifting of the coastal populations from areas where they lived under conditions of maximum exposure to filarial infection to new areas where conditions are totally unfavourable for the transmission of the infection or, if transmission is possible, it is not intensive enough for the establishment of hyperfilariation in the human host. It would be of interest to describe the conditions that prevailed in the coastal areas of New Caledonia during the last century and the changes that have since taken place.

Till the close of the last century, a considerable part of the population of New Caledonia lived in sprawling villages along the sea coast, usually within or at the margins of extensive mangrove swamps. The swamps provided them with fish and shell-fish, and the soggy land at the edge of the marsh was suitable for the cultivation of taro. For bringing land under cultivation, the areas naturally covered with dense mangrove vegetation in the vicinity of the villages were extensively cleared, often by setting fire to the bush. Progressive denudation of the mangrove forests in and around villages was also brought about through the demands for fuel for domestic use. The clearing of the mangrove vegetation resulted in the exposure of the brackish and saline pools to sunshine, thereby rendering them highly favourable for Aedes vigilax to breed. As the villages were situated close to or even within large saline marshes which have been rendered suitable for the breeding of A. vigilax through the clearing of the mangrove vegetation, the two conditions necessary for intensive transmission of filarial infection were fulfilled, namely high vector density and proximity of vector breeding sites to habitations. Under such conditions, hyperfilariation in man was frequent, and a high incidence of elephantiasis prevailed among the coastal populations.

New Caledonia was annexed by the French in 1853. At that time the total native population was estimated at about 70,000. As a result of contact with the Europeans, various communicable diseases like influenza, measles, small-pox and mumps, broke out in epidemic form among the natives of New Caledonia, especially of the coastal areas, resulting in heavy mortality. The superstitious natives, attributing the diseases to residence in their old villages, tried to move into new areas, but their attempts to migrate into the inland areas were met with fierce opposition from the hostile tribes of the interior. Following on these epidemics came the decision of the French

Government to use New Caledonia as a convict settlement. The use of New Caledonia as a convict settlement started in 1864, and large numbers of convicts, estimated at over 40,000, were transported to New Caledonia between 1864 and 1894. The island was also thrown open for free colonists to settle. The convicts who had served out their sentences were, as "libérés", given land and allowed to settle alongside free colonists, most of whom turned to cattle-grazing for a living. Various acts such as confiscation and expropriation of native lands, damage caused to native property and plantations by the convicts, the settlers, and the cattle owned by them, and other horrors common to penal settlements, led to a ferocious native revolt on 25th June 1878, and a second insurrection during 1881. These were followed by very severe reprisals by the French armed forces, who moved from one coastal village to another, set fire to the villages, destroyed the gardens and plantations, and rounded up the coastal tribes. The captured natives were forcibly settled in trival reserves in the interior, and kept under the strict surveillance of the army and the police. Another, though smaller, native uprising occurred in 1917, led by Noel of Pomale, and the punitive action taken by the French Government further accentuated the exodus of the native tribes from the coastal areas into the interior. Sites of abandoned native villages and ruins of houses are still to be found in several of the coastal areas of New Caledonia. Some of the less hostile tribes were however allowed to resettle on selected new sites along the coast close to police stations or mission stations so as to be under surveillance. These new coastal settlements, unlike the original coastal villages, were sited mostly on dry terrain, usually at considerable distances from mangrove swamps.

The changes that had taken place during the period 1880 to 1918, namely the shifting of the coastal population into the interior, and in a few instances to selected sites along the coast not too close to mangrove swamps, have been responsible for the regression in the incidence of elephantiasis and other manifestations of filarial disease. In the populations that were moved into the interior reserves or to coastal sites far from mangrove swamps, contact with the vector mosquito was broken with the result that both filarial disease and filarial infection have died out in such communities. In a few of the coastal settlements that happen to be situated comparatively close to mangrove swamps, endemic filarial infection occurs in the populations of such settlements, the incidence of the infection varying in direct relation to local vector density and proximity of the vector breeding sites to the habitations; but in view of the fact that these foci are not located in the immediate vicinity of mangrove swamps breeding A. vigilax, opportunities for hyperfilariation are poor and in consequence filarial disease is practically absent. Under the existing conditions, filarial disease is not a problem of importance in the New Caledonian zone, even though W. bancrofti infection is endemic in a number of foci.

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XI. RECAPITULATION AND DISCUSSION

Endemic filarial infection in the South Pacific consists of one or the other of the two biological races of Wuchereria bancrofti, the periodic and the non-periodic. The periodic race is adapted for transmission by certain night-biting mosquitoes; its microfilaria exhibits characteristic nocturnal periodicity in the peripheral blood of the human host. The non-periodic race of W. bancrofti finds its most favourable intermediate host in certain species of day-biting mosquitoes; its microfilaria does not exhibit nocturnal periodicity and occurs in the peripheral blood in more or less equal numbers at all hours of the day and night. The two races are not morphologically distinct, and there is no evidence to show that they differ in their pathogenecity.

The ranges of geographical distribution of the two races are distinct. Periodic W. bancrofti has a range covering the Micronesian Islands on the north, and certain Melanesian islands (New Guinea, Bismarck Archipelago, Solomon Islands and New Hebrides) on the west. Non-periodic W. bancrofti occurs in the eastern section of the South Pacific (from Fiji and Ellice Islands to the eastern limit of the region), and in New Caledonia and the Loyalty Islands in the south-west.

Within the range of distribution of periodic W. bancrofti are two well-defined areas: (1) the Micronesian area with a strain of periodic W. bancrofti transmitted by Culex (Culex) pipiens fatigans, and (2) the Papuan area with a strain of periodic W. bancrofti transmitted mainly by three species of the Anopheles punctulatus group, namely Anopheles (Cellia) farauti, A. (C.) koliensis and A. (C.) punctulatus. The range of distribution of the non-periodic race of W. bancrofti includes two distinct areas: (1) the Polynesian area where the vectors are five species of the Aedes scutellaris group, namely Aedes (Stegomya) polynesiensis, A. (S.) pseudoscutellaris, A. (S.) tongae, A. (S.) rotumae, and A. (S.) cooki; and (2) the New Caledonian area where the vector is Aedes (Ochlerotatus) vigilax.

As these vector species differ in their bionomics and breeding habitats, the factors controlling filarial endemicity vary from one area to another. On the basis of the type of W. bancrofti infection present and the vectors concerned in the transmission, four epidemiological zones may be differentiated as follows:

(a) The Micronesian zone with periodic W. bancrofti transmitted by Culex fatigans;

(b) The Papuan zone with periodic W. bancrofti transmitted mainly by species of the Anopheles punctulatus group;

(c) The Polynesian zone with non-periodic W. bancrofti transmitted by certain species of the Aedes (Stegomya) scutellaris group; and

(d) The New Caledonian zone with non-periodic W. bancrofti transmitted by Aedes (Ochlerotatus) vigilax.

(a) Micronesian Zone

The strain of periodic W. bancrofti occurring in the Micronesian zone (comprising the Mariana Islands, Carolines, Marshalls, Gilberts, Nauru, and Ocean Island), is akin to the Asiatic strain and is transmitted by Culex fatigans. The distribution of filarial infection within this zone is very uneven. The Mariana Islands are practically free from the infection except for the endemic focus on Saipan Island. In the Carolines, endemic filarial infection is widespread, the incidence of the infection varying markedly in the different islands of the group. Some of the islands are free from the infection except for sporadic cases; in the majority of the islands, microfilaria rates range between 17 and 27 per cent, and a few like Satawal and Babeldob have even higher microfilaria rates (32 and 37 per cent respectively). Broadly speaking, microfilaria rates are high in the islands of the western and central sections of the Carolines, and low in the eastern section. In the Marshall Islands to the east of the Carolines, endemic filarial infection occurs only sporadically, most of the islands being free; the infection is known to occur only in two islands, namely Majuro and Namorik, and even in these, the microfilaria rates are very low, less than 4 per cent. In the Gilbert Islands situated to the south of the Marshall Islands, filarial infection is present in nearly all the islands of the group. In the islands of the northern part of the Gilberts, namely Makin, Butaritari and Abaiang, filarial infection is absent or occurs only sporadically; in the islands of the central section of the Gilberts, microfilaria rates are between 6 and 13 per cent, and somewhat higher in the islands of the southern section. In Nauru Island, to the west of the Gilberts, the microfilaria rate is 29 per cent.

The general incidence of filarial disease in the Micronesian zone is very low. Filarial disease is practically absent in the Marianas and Marshall Islands. In the Caroline Islands, cases of filarial disease are rare and only sporadic in occurrence even in the western section of the group where high microfilaria rates have been recorded. In the Gilbert Islands, endemic cases of filarial disease are known to occur, especially in the southern section of the group; the elephantiasis rate is however very low, 0.5 per cent or less, but cases of filarial lymphangitis and hydrocele are more common. The only area in the Micronesian zone with an appreciable incidence of filarial disease is Nauru; here, 1.4 per cent of the population suffer from elephantiasis, and other manifestations of filarial disease like lymphangitis and hydrocele are fairly common. In the Micronesian zone, filarial disease appears to be restricted to areas with high population density and low rainfall, namely the southern Gilberts and Nauru.

Culex fatigans, the vector of W. bancrofti in the Micronesian zone, is an anthropophilic species, feeding primarily on man, resting in dwelling houses, and breeding in collections of contaminated water close to human habitations. It is unusual for this mosquito to breed in areas away from the villages, or in water collections that are free from decaying organic matter. Its main breeding sites are ground pools, ditches and shallow wells. The shallow wells in the porous soil are subject to organic contamination and constitute perennial breeding sites in the villages of this zone.

The concentration of decaying organic matter in the water of breeding sites determines the intensity of C. fatigans breeding. The extent of organic contamination in the breeding sites is directly related to density of human population. Consequently, villages with large populations have higher prevalence of C. fatigans than those with small populations. Villages situated on undulating land have fewer surface collections of water, and the deep wells in these villages are not subject to surface contamination to any appreciable extent; the incidence of C. fatigans in such villages is low. Heavy rainfall has the effect of reducing the intensity of C. fatigans breeding by lowering the concentration of organic matter in the water of potential breeding sites; areas with heavy rainfall have a comparatively low incidence of C. fatigans.

The microfilaria rates of the different inhabited areas vary in direct relation to the local density of prevalence of the vector mosquito, and this in turn depends on the three factors, density of human population, nature of terrain, and amount of rainfall. High microfilaria rates are commonly associated with villages situated on low-lying flat land, having large populations and low rainfall.

It was mentioned that the general incidence of filarial disease in the Micronesian zone is low, even though filarial infection is widespread and the microfilaria rates are often high. Of the two conditions essential for intensive transmission of filarial infection, namely (1) proximity of vector breeding sites to habitations, and (2) high vector density, the first is fulfilled in the inhabited areas of this zone; Culex fatigans breeds invariably within or close to the villages. The second condition is not fulfilled in the vast majority of the villages. The density of human population in these rural areas is not high enough to cause heavy pollution of the water in breeding sites, and consequently vector density does not reach the level necessary for intensive transmission and establishment of hyperfilariation in man. While vector density in the endemic foci is high enough to ensure transmission and maintenance of microfilaraemia in the population, it is not sufficiently high to produce an appreciable incidence of filarial disease. The only area with a significant incidence of filarial disease is Nauru, with an elephantiasis rate of 1.4 per cent and a hydrocele rate among males of 10 per cent. In Nauru, the density of population in the congested labour settlements is high, heavy breeding of C. fatigans occurs in the numerous collections of sullage-contaminated water, and the prevalence of adult mosquitoes in the habitations is high.

(b) Papuan Zone

The Papuan zone comprises New Guinea, Bismarck Archipelago, Solomon Islands and New Hebrides. Filarial infection endemic in this zone is the Papuan strain of periodic W. bancrofti, which is distinct from the classical strain in that Culex fatigans, the customary vector of the latter strain, is not a favourable host. Taking the Papuan zone as a whole, the major vectors are three species of the Anopheles punctulatus group, namely Anopheles farauti, A. koliensis, and A. punctulatus. In certain parts of

New Guinea, other species like Mansonia uniformis, Culex annulirostris, C. bitaeniorhynchus, Anopheles bancroftii and Aedes kochi, transmit the infection either by themselves or in association with species of the Anopheles punctulatus group. Except for these foci in New Guinea, in all other parts of this zone, the vectors are one or more of the three species Anopheles farauti, A. koliensis and A. punctulatus. Their main breeding sites are ground pools and marshes exposed to sunshine.

Endemic filarial infection has a wide distribution in the low-lying flat areas of the Papuan zone. The undulating and hilly areas are free from the infection. In the different foci the microfilaria rates (all ages) vary between 2 and 27 per cent. The incidence of the infection bears a direct relation to local vector density and nearness of vector breeding sites to the villages. High microfilaria rates are common in villages situated close to extensive breeding sites of the vectors, as for example those located in or near shallow marshes, and those close to blocked mouths of streams.

As the three major vectors of W. bancrofti in the Papuan zone are also efficient vectors of malaria, endemic filarial infection co-exists with endemic malaria practically throughout this zone, barring certain areas in New Guinea with W. bancrofti transmitted solely by culicine vectors. By and large, there is a parallel incidence of endemic W. bancrofti infection and endemic malaria. Whereas all areas with W. bancrofti transmitted by these anopheline vectors are also endemic for malaria, the converse does not hold good. Not all areas with endemic or even hyperendemic malaria have endemic filarial infection. Even in regard to altitude, the range of endemic malaria is much greater than that of endemic filarial infection; the latter is not known to occur at elevations of more than 500 feet, whereas endemic malaria is known to occur upto elevations of as much as 4000 feet. Although the same vectors are responsible for the transmission of both malaria and W. bancrofti, the restriction of the latter to foci within a much wider belt of endemic malaria is due to the fact that it requires more intensive transmission for the establishment of endemic filarial infection than is needed for maintaining endemic malaria. Such conditions obtain only in areas with high vector density and with extensive breeding sites close to habitations.

Filarial disease is prevalent in a large proportion of the areas with endemic filarial infection. The common manifestations are filarial lymphangitis and hydrocele. Elephantiasis is of less frequent occurrence, and its incidence is rarely more than 3 per cent. The cases of elephantiasis are mostly of the mild type, and multiple lesions in such cases are rare. The exceptions are the New Guinean foci, namely Inanwatan, Pam Island and Telaga Kokoda villages, with W. bancrofti transmitted solely or primarily by culicine vectors. In these foci, elephantiasis rates are very high, 5 to 8 per cent, and many of the cases of elephantiasis show multiple lesions and gross enlargement of the limbs and scrotum. This is because chances of hyperfilariation are ordinarily greater where culicines are the vectors, than where Anopheles farauti and allied species are the vectors. The breeding sites of the culicine vectors often occur very close to habitations, and the intensity of breeding is high, the organic pollution of the water favouring heavy breeding. The breeding sites of Anopheles farauti rarely occur very close to villages, its breeding intensity is not high, and potential breeding sites in the vicinity of habitations are often rendered unsuitable as a result of organic pollution of the water.

The incidence of filarial disease in the different foci varies in relation to the two factors, vector density and nearness of vector breeding sites to habitations. Villages with high vector density and with vector breeding sites close by have a high incidence of filarial disease. Where either vector density is low, or the breeding sites are not sufficiently close to the village, endemic filarial disease is practically absent, even if a significant proportion of the population shows microfilaraemia.

(c) Polynesian Zone

In the Polynesian zone extending from Fiji, Rotuma and Ellice Islands to the Marquesas and Tuamotu Islands, endemic filarial infection consists of the non-periodic race of W. bancrofti, and the vectors are five species of the Aedes (Stegomya) scutellaris group, namely Aedes polynesiensis, A. pseudoscutellaris, A. tongae, A. rotumae, and A. cooki. Of these, A. polynesiensis has the widest distribution in this zone and occurs on all the islands with the exception of Rotuma, Tonga and Niue; in these three areas, the respective vectors are A. rotumae, A. tongae, and A. cooki. In Fiji, both A. polynesiensis and A. pseudoscutellaris are the vectors of W. bancrofti.

All the five vectors are day-biting, exophilic species, resting outdoors in low bush, and feeding mostly outdoors; not infrequently, they enter houses to feed on man, especially if breeding sites occur close by. They have a very short range of flight, and are rarely to be found at distances of more than 100 yards from breeding sites; while this may be taken as the maximum distance that the mosquito could travel, ordinarily it does not stray farther than 50 yards from its breeding site, and generally tends to stay in its immediate vicinity.

The density of prevalence of the vector depends on the profusion of breeding sites in the locality. In village areas, the main breeding sites are artificial containers like barrels for storing rain-water, coconut shells and discarded tin-cans. In most parts of the Polynesian zone the people depend on collected rain-water for their supply of fresh water. Rain-water collected from roofs of houses as catchment is stored in drums, barrels and a variety of receptacles. Every household has several such containers in which the Aedes mosquito breeds practically all through the year. In the peri-domestic areas there are often large accumulations of coconut shells and tin-cans which are commonly dumped into bush adjoining houses. Aedes breeds in the rain-water collecting in these small containers, the extent of breeding depending on the amount of rainfall. In bush and plantation areas, Aedes breeds in tree-holes and rat-damaged coconuts. Of these, the more prolific and frequently the more numerous breeding site is the rat-damaged coconut. Rats cause heavy damage to coconuts, estimated at 20 to

60 per cent of the coconut crop on the different islands of this zone. The ground in coconut plantations is often heavily littered with large numbers of rat-damaged coconuts.

The vector mosquito occurs in inhabited as well as in uninhabited areas, since opportunities for its breeding are present everywhere. However, the areas of primary importance from the point of view of transmission of filarial infection are those where there is constant contact of the vector with the human population. Contact with man is essential for the vector to derive filarial infection from the human reservoir and later, when the infection has reached the infective stage, for the infective mosquito to transmit the infection to man. Opportunities for the vector to acquire filarial infection and to transmit it to man are greatest in the domestic and peridomestic environment where the local vector population has continuous contact with man. In bush and plantation areas not inhabited by man, chances of transmission are extremely poor. The vector population of uninhabited areas has little opportunity to feed on man, and even fewer opportunities of obtaining an infective blood meal. Any infection that may have been fortuitously acquired by the mosquito in such areas cannot be transmitted to man unless that area is visited again by man after the period of incubation needed for the infection in the mosquito host to reach the infective stage. Transmission of filarial infection in plantation areas is possible only when people camp in the same locality for periods longer than two weeks, or if they visit the same areas regularly from day to day. We know of several areas in the Polynesian zone where, under such conditions, transmission takes place in bush and plantations. However, the extent of transmission occurring there is small in comparison with permanently inhabited areas where there is continuous contact of the vector with the human population. In the latter areas, a high incidence of natural infection occurs in the vector, the infected mosquitoes carry large numbers of filaria larvae, and many of the infected specimens carry more than a single brood of the parasite. Such findings are rare among mosquitoes caught in uninhabited bush and plantation areas, even in those regularly visited by man. These observations show that the areas of primary importance as regards exposure to filarial infection are those where there is continuous contact of the vector with man, and such contact occurs only in the domestic and peri-domestic environment.

Filarial infection is widespread in the Polynesian zone, and occurs everywhere excepting a few small islands. The microfilaria rates (all ages) vary between 5 and 40 per cent. Filarial disease is prevalent in the majority of the island groups. There are however a number of islands that are remarkably free from endemic filarial disease although with moderate to high incidence of filarial infection, as for example the Austral Islands, Tokelau Islands, islands of the Tuamotu Archipelago, and the atoll islands of the northern Cook group.

In the villages of the Austral Islands, the vector mosquito Aedes polynesiensis occurs in sufficient numbers for transmission to occur. The microfilaria rates of the different areas vary between 9 and 21 per cent. The intensity of infection in the microfilaria carriers is low, and endemic filarial disease is absent. Vector density in the villages of the Australs, while sufficient to maintain microfilaraemia of a low grade in an appreciable proportion of the population, is not high enough for intensive transmission necessary for the establishment of hyperfilariation in the human host.

In Tokelau Islands, Tuamotu Archipelago and the atoll islands of the northern Cook group, the people are free from exposure to infection while residing in the village, whereas they are exposed to infection when they camp in the plantations areas. Each of these islands is an atoll consisting of a ring of tiny islets surrounding a large lagoon. In each island, the people live on a single islet, known as the village islet. This islet is maintained in a scrupulously tidy condition and practically free from vector breeding sites. The vector mosquito is rarely to be seen on the village islet, and the people are not exposed to filarial infection within the village environment. The other islets of the atoll are reserved as plantations. In the plantation islets, which are periodically visited by the people for collecting copra, a very high incidence of the vector mosquito prevails. Although no one resides permanently on the plantation islets, as the people often stay there long enough for transmission of filarial infection to take place, filarial infection is present among the populations of these islands. In the Tuamotus the microfilaria rates are between 1 and 18 per cent, in the Tokelau Islands between 14 and 22 per cent, and in the atoll islands of the northern Cook group between 6 and 20 per cent. In all these areas, the intensity of infection in the microfilaria carriers is low. Since exposure to infection is absent in the domestic environment, and occurs only intermittently and not intensively in the plantations, opportunities for hyperfilariation are rare, and endemic filarial disease is virtually absent.

In most of the other inhabited areas of the Polynesian zone, vector density in the village environment is high. Numerous breeding sites of the vector mosquito occur in the domestic and peri-domestic areas, the important ones being containers for storing rain-water and litter like coconut shells and tin-cans. In these areas the microfilaria rates are high, from 18 to 40 per cent, and the general intensity of infection in the microfilaria carriers is high. Conditions are favourable for continuous and intensive transmission, hyperfilariation is frequent, and endemic filarial disease is common. Elephantiasis rates are generally over 2 per cent, and often as high as 4 to 7 per cent.

Wherever the extent of vector breeding in the village environment had been reduced as a result of either aggregation of human population, or measures of general sanitation, there has been a progressive regression in the incidence of filarial disease, and frequently a regression even in the incidence of filarial infection. Urban and quasi-urban areas have low microfilaria rates in comparison with the surrounding rural areas, and little of endemic filarial disease. Marked reduction in the incidence of filarial disease as also in the severity of its manifestations has been noted in many areas subsequent to the introduction of piped water supply and the provision of communal cisterns for rain-water; these measures served to reduce vector density in the village environment by eliminating the domestic container for

rain-water, a perennial breeding site of the Aedes mosquito in inhabited areas. Measures for collection and disposal of litter have a similar effect through eliminating breeding sites like coconut shells and tin-cans in the village areas.

(d) New Caledonian Zone

In the New Caledonian zone, comprising New Caledonia and the Loyalty Islands, endemic filarial infection consists of the non-periodic race of W. bancrofti, and the vector is Aedes (Ochlerotatus) vigilax, a salt-marsh breeder. Aedes vigilax breeds intensively in stagnant, shallow pools of brackish or saline water exposed to sunshine. Clearing of mangrove vegetation renders saline water collections, which were previously innocuous because they were shaded by vegetation, favourable for Aedes vigilax to breed. The optimum range of salinity of the water for A. vigilax to breed is between 1 and 2.6 per cent chlorides. Heavy rainfall, through lowering the salinity of the water in breeding sites, has the effect of reducing the intensity of breeding of this mosquito. The prevalence of A. vigilax shows a marked seasonal variation; it is most numerous during periods when temperature is high and rainfall is not excessive.

Although Aedes vigilax, which has a long range of flight, occurs in large numbers in the coastal areas of this zone as well as in the hinterland, endemic filarial infection is restricted in its distribution to a number of isolated coastal foci that are situated comparatively close to saline marshes breeding this mosquito. In the different endemic foci, the microfilaria rates vary widely, from 4 to 37 per cent. A remarkable feature of these foci is the rarity of cases of filarial disease, even in those with high microfilaria rates. Evidently, conditions existing in these foci are favourable for transmission of filarial infection and maintenance of endemic microfilaraemia in the population, but transmission is not intensive enough to produce an appreciable incidence of filarial disease.

In striking contrast to the present rarity of cases of filarial disease in the endemic foci of the New Caledonian zone, elephantiasis and other manifestations of the disease were extremely common among the coastal populations of this zone some 80 years ago. Observers of that period recorded the high incidence of the disease and the finding of numerous cases of gross elephantiasis of the limbs and enormous scrotal tumours. At that time, the coastal villages were located within or in the immediate vicinity of saline marshes that had been largely cleared of mangrove vegetation and rendered favourable for heavy breeding of Aedes vigilax. Because of the high vector density and the close proximity of breeding sites to habitations, the people were exposed to intensive infection which led to hyperfilariation; as a result, a high incidence of filarial disease was prevalent. During the later part of the last century and the early decades of the present century, certain events took place which led to the shifting of the coastal populations from areas where they were exposed to intensive infection, to new areas mostly in the interior where such conditions do not prevail. In communities that were moved into interior areas as also in those that were shifted to coastal areas away from saline marshes, filarial disease as well as filarial infection died out, even though many of these new villages are infested with large numbers of Aedes vigilax. In communities that were settled on coastal sites comparatively close to saline marshes breeding the vector mosquito, endemic filarial infection is present, the incidence of the infection in the population varying in relation to the proximity of the habitations to vector breeding sites. Unlike the old coastal villages which were located within or at the edge of saline marshes, these new coastal villages are situated on dry terrain at a short distance from the marshes, and although transmission of filarial infection occurs in these villages, they are not close enough to the vector breeding sites to facilitate intensive transmission necessary for the establishment of hyperfilariation in man, and in consequence filarial disease is rare.

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Taking the South Pacific as a whole, the inhabited areas vary widely in the incidence of filarial infection and of filarial disease. There are areas that are wholly free from endemic filarial infection. There are many with a varying incidence of filarial infection but virtually free from endemic filarial disease. There are others which have a significant incidence of filarial disease. These variations are directly related to the extent to which local conditions are favourable for the transmission of filarial infection.

Three factors are of importance in the transmission of filarial infection, namely:

1. Occurrence of climatic conditions favourable for the development of the filaria parasite in the mosquito host;

2. The occurrence of high vector density in contact with the human population; and

3. Proximity of vector breeding sites to human habitations.

In the vast majority of the inhabited areas of the South Pacific, climatic conditions are favourable for the transmission of filarial infection, namely the uniform high temperatures with little seasonal variation, and the high atmospheric humidity, which are favourable respectively for the rapid completion of the extrinsic development of the filaria parasite and for prolonging the survival time of the mosquito host. On the other hand, there is considerable variation from one area to another in regard to the other two factors, namely vector density in contact with the human population, and proximity of vector breeding sites to habitations, which account for the differences in the local filarial endemicity.

The extent of transmission is directly related to the local vector density. High vector density is necessary in order that a large number of mosquitoes would have the opportunity to acquire the infection from the human reservoir, so as to allow for the loss of potentially infective mosquitoes during the period of incubation of the parasite in the mosquito host. In the absence of high vector density, the chances of transmission are poor. The higher the vector density, the greater is the extent of transmission.

Vector density depends on the presence of breeding sites suitable for the species concerned, the intensity of breeding in those sites, and their proximity to human habitations. The dispersal of mosquitoes from a breeding site is inversely proportional to the distance, so that habitations situated close to breeding sites have higher density of adult mosquitoes than those that are farther away. Proximity of habitations to breeding sites enables the female mosquito to obtain a blood meal readily, and when the ova mature the gravid female has within easy reach a suitable breeding site in which to oviposit; such conditions favour heavy breeding of the mosquito and continuous output of imagines.

Climatic factors have a large bearing on the intensity of vector breeding. High temperatures favour rapid development of the larval stages and increased output of adult mosquitoes, while low temperatures retard larval development and decrease imaginal output. Extremely low rainfall and drought conditions reduce the extent of mosquito breeding through drying up of potential breeding sites. Heavy rainfall offers increased facilities for the breeding of species like Aedes polynesiensis; on the other hand, heavy rainfall reduces the intensity of breeding of Culex fatigans through lowering the concentration of organic matter in the water of breeding sites, and of Aedes vigilax by lowering the salinity of the water.

Frequently, man creates breeding sites suitable for the vector mosquito or, through his activities, renders existing water collections favourable for the breeding of the vector. The following are a few examples. Maintenance of domestic containers for storing rain-water, and careless disposal of litter like coconut shells and tin-cans offer facilities for the breeding of Aedes polynesiensis and allied species. Contamination with sullage of water collections in the vicinity of habitations renders them favourable for Culex fatigans to breed. Pollution with excreta, of water in shallow marshes facilitates intensive breeding of species like Mansonia uniformis, Culex annulirostris and C. bitaeniorhynchus, as was noted in the villages of the Telaga Kokoda marsh. Impounding of water by blocking the mouths of streams to conserve water offers increased opportunities for the breeding of Anopheles farauti. Obstruction to the natural flow of water in tidal channels favours intensive breeding of Aedes vigilax. Exposure of water collections to direct sunshine by clearing of bush and mangrove vegetation renders them suitable for the breeding of species like Anopheles farauti and Aedes vigilax.

Continuous contact of the vector with man is necessary firstly for the mosquito to acquire filarial infection from the human reservoir and secondly, when the infection in the mosquito host has reached the infective stage (after the extrinsic incubation period of the parasite), for the infective mosquito to transmit the infection to man. Where such contact is lacking, transmission is not likely to occur. Opportunities for transmission are greatest in and around human habitations, because in such situations the local vector population has continuous contact with man, which enables the vector to derive the infection from microfilaria carriers and later to transmit the matured infection to man. In uninhabited areas, even if high vector density prevails, because of lack of contact with man the local vector population has little chance of deriving filarial infection, as also of transmitting to man any infection that may have been fortuitously acquired. Transmission is possible in uninhabited areas only when the same area is visited regularly by man, or if people happen to camp in any one area for prolonged periods.

Proximity of vector breeding sites to habitations, besides favouring high vector density, is of great importance for transmission of filarial infection. Unless the breeding site is close to the village and within the range of flight of the vector mosquito, transmission is not feasible. Under conditions of gonotrophic concordance, which is the normality with mosquitoes in the tropics, a blood meal is followed by maturation of ova and the necessity for the gravid female to visit a breeding site suitable for the species concerned, for the purpose of oviposition. Except for the maturation of the first batch of eggs which, in the case of some species, may require two blood meals, every blood meal is followed by the maturation of a batch of eggs. The need for oviposition on the maturation of eggs following every blood meal necessitates frequent flights to and fro between the village which is the site of feeding, and the breeding place, the site of oviposition.

The ranges of flight of the different vector species vary considerably. Aedes polynesiensis, for example, is known to have a very short range of flight, often stated to be not more than 100 yards. Culex fatigans has a medium range of flight, while Aedes vigilax has a very long range of flight; the latter species has often been found to occur in large numbers even at distances of several miles from its breeding site. These flight ranges refer ordinarily to the distance that the unfed nulliparous female is able to travel during her maiden flight in search of a blood meal soon after emergence from the breeding site. They indicate the potential power of flight of the species in the nulliparous state, and although of importance from the point of view of dispersal of the species as also sometimes of causation of mosquito nuisance, they are not important from the point of view of transmission of filarial infection.

The power of flight of a mosquito varies at different stages of its life. It is greatest in the unfed nulliparous female which has high buoyancy; her ovaries are small and in an undeveloped state, the ovarioles are minute and in the earliest stage of development, and she is not loaded with a blood meal. Engorgement with a blood meal effects an immediate overloading and greatly reduces her power of flight. As the blood meal is being digested, the ovaries develop simultaneously and the ova reach maturity within a few days. The load of matured eggs reduces the power of flight of the gravid female, and for oviposition she reaches the breeding site by easy stages. Even after oviposition and relieving herself of the load of matured eggs, she does not regain the buoyancy of the nulliparous state because the ovaries have

reached a size many times larger than originally, and the next series of ovarian follicles is developing towards maturation. Consequently, the parous female, even when not loaded with a blood meal or with matured eggs, has a considerably smaller range of flight than that of the nulliparous female of the same species, and she is incapable of travelling the distances she was able to do during her maiden flight. Subsequent to the first oviposition, she is interested only in the most accessible source of blood meal in the proximity of a breeding site and rarely strays far from it.

In tropical conditions, the duration of the gonotrophic cycle of the mosquito, namely one round of ovarian development from the time a blood meal is taken to the time the matured eggs are oviposited and the mosquito is ready for the next blood meal, is 2 to 3 days. The extrinsic incubation period of the filaria under optimum temperature and humidity conditions is about 12 days (range 10 to 14 days). During the time needed for the filaria parasite to reach the infective stage in the mosquito host, the mosquito may have to undertake three to four flights to the breeding site and back to the village, taking the duration of the gonotrophic cycle as 3 days. During each of these gonotrophic flights, the potentially infective mosquito runs the risk of death as also of scatter away from the village. The greater the distance that has to be covered, the greater are the hazards that the mosquito would encounter, and the chances of her survival until such time as the filarial infection acquired by her reaches maturity and of her returning to the village to transmit the matured infection to man are proportionately less.

A further factor to be taken into consideration is the effect of filarial infection on the power of flight of the mosquito. Larvae of W. bancrofti developing within the thoracic musculature of the mosquito cause considerable damage to the muscle strands and thereby impair its power of flight. Sections of filariated mosquitoes demonstrate the damage caused to the thoraci[c] muscles around developing filaria larvae. Such damage is greater in mosquitoe[s] infected with large numbers of filaria larvae than in those with light infections. In the adult mosquito there is no regeneration of muscles that have been damaged or destroyed, so that the impairment of its power of flight brought about by such parasitism is permanent. The power of flight of the parous mosquito infected with larvae of W. bancrofti is markedly less than that of the uninfected parous female of the same species.

The "effective range of flight" of a vector mosquito, for transmissio[n] of filarial infection to be feasible, would be the distance that a parous female infected with larvae of W. bancrofti could travel during her gonotrophic flights between the site of feeding and the site of oviposition. We lack precise information on the effective flight ranges of the different vectors of W. bancrofti in the South Pacific from the point of view of transmission of the infection. Based on epidemiological observations made in different parts of the South Pacific, the effective flight ranges of the important vectors may be presumed to be roughly as follows: Aedes polynesiensis, 25 to 40 yards; Culex fatigans, 100 to 200 yards; Anopheles farauti, 200 to 300 yards; and Aedes vigilax, 300 to 400 yards.

Transmission of filarial infection is possible only if the distance between human habitations and vector breeding sites is less than the effective flight range of the local vector species. The degree of proximity of vector breeding sites to habitations determines the intensity of transmission, which in turn reflects itself in the local filarial endemicity. Where the degree of proximity of vector breeding sites to habitations is such as to favour only a low intensity of transmission, insufficient to produce hyperfilariation in man, endemic filarial infection occurs in the community in the absence of filarial disease. Where the degree of that proximity is greater, transmission would be more intensive, so that hyperfilariation in man would be frequent and filarial disease would occur in the community.

The intensity of transmission occurring in an area depends on the extent to which the two conditions necessary for transmission are fulfilled, namely high vector density in contact with man and proximity (with respect to the effective flight range of the vector species concerned) of vector breeding sites to habitations. Where the village environment is free from vector breeding sites, endemic filarial infection is absent, even if there is influx of large numbers of the vector mosquito from breeding sites far from the village. Likewise, if vector density is low, endemic filarial infection is rare even though vector breeding sites occur close to habitations. If people living in a village environment which is free from vector breeding sites or in which vector density is not high enough for transmission, are exposed to infection in bush and plantation areas visited by them from time to time, filarial infection is present in such communities, but as exposure to infection is not intensive and continuous, filarial disease is virtually absent, as for example in Tokelau Islands, Tuamotu Islands and the atoll islands of the northern Cook group. In areas with vector breeding sites close enough to habitations to facilitate transmission but not sufficiently near for intensive transmission, filarial infection is present but filarial disease is rare, e.g., the majority of the endemic foci in Solomon Islands, New Hebrides and New Caledonia, and many of the foci in New Guinea. Where vector breeding sites occur very close to habitations but vector density, though high enough for transmission, is not sufficiently high for intensive transmission, filarial infection is present but cases of filarial disease are rare, e.g., the endemic foci of Caroline Islands and Austral Islands.

In the instances enumerated above, conditions in the village environment are such that they are not favourable for intensive transmission of filarial infection, and even if the infection is present in these communities, endemic filarial disease is absent or rare. Filarial disease is prevelent only in areas where vector breeding sites occur close to habitations, at distances considerably less than the effective flight range of the local vector mosquito, and the output of imagines from the vector breeding sites is large enough for maintaining high vector density in the village environment. Under such conditions, transmission is intensive and continuous, hyperfilariation in man is frequent, and a significant incidence of filarial disease prevails. The higher the vector density and the closer the vector breeding sites to habitations, the greater is the incidence of filarial disease in the community.

Changes which directly or indirectly effected a reduction in the extent of vector breeding in the village environment or increased the distance between the human habitations and the vector breeding sites, have brought about a marked regression in the incidence of filarial disease in communities in which the disease was erstwhile highly prevalent. Two notable examples are the following. In parts of the Polynesian zone that have been provided with piped water supply, there has been a marked regression in the incidence of filarial disease and in the severity of its manifestations, which is attributable to the elimination of the domestic container for storing rain-water, an important source of <u>Aedes polynesiensis</u> in the village environment. In New Caledonia, the shifting of coastal populations from the vicinity of saline marshes breeding the local vector, <u>Aedes vigilax</u>, to areas distant from such marshes has resulted in the disappearance of filarial disease which was formerly rampant in those communities.

These observations show that the conditions prevailing in the domestic and peri-domestic environment in regard to the extent and intensity of breeding of the local vector mosquito determine the prevalence of filarial disease, which is the important consideration from the public health standpoint.

(Continued from outside back cover)

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40. Cocoa Growing in New Hebrides. D. H. Urquhart. January 1953. (E).
55. Le Conditionnement des fruits frais exportés des territoires du Pacifique Sud. April 1954. (F).
82. The Manufacture of Copra in the Pacific Islands. W. V. D. Pieris. July 1955. (6/- stg., $A0.75, 6/9F., $US0.90). (EF).
87. L'agriculture vivrière autochtone de la Nouvelle-Calédonie. Jacques Barrau and Jean Guiart. January 1956. (20/- stg., $A2.50, 22/6F., $US3.00). (F).

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