Mosquitos and malaria : a summary of knowledge on the subject up to date with an account of the natural history of some mosquitos / by Cuthbert Christy.

Contributors

Christy, Cuthbert, 1863-1932.

Publication/Creation

[London] : Sampson, Low, Marston, 1900.

Persistent URL

https://wellcomecollection.org/works/cguj4cdv

License and attribution

This work has been identified as being free of known restrictions under copyright law, including all related and neighbouring rights and is being made available under the Creative Commons, Public Domain Mark.

You can copy, modify, distribute and perform the work, even for commercial purposes, without asking permission.

wellcome collection

Wellcome Collection
183 Euston Road
London NW1 2BE UK
T +44 (0)20 7611 8722
E library@wellcomecollection.org
https://wellcomecollection.org

TRO
WC750
1900
C55m

22101015771

MOSQUITOS AND MALARIA.

MOSQUITOS AND MALARIA

A SUMMARY OF KNOWLEDGE ON THE SUBJECT UP TO DATE; WITH AN ACCOUNT OF THE NATURAL HISTORY OF SOME MOSQUITOS.

BY

CUTHBERT CHRISTY, M.B. & C.M. (EDIN.),

Special Medical Officer on Plague Duty for the Indian Government; Late Senior Medical Officer, West African Frontier Force, Nigeria.

WITH SIX FULL-PAGE PLATES.

London:

SAMPSON LOW, MARSTON AND COMPANY, LTD

BOMBAY: THE "TIMES OF INDIA" PRESS.

1900.

HAYMAN, CHRISTY AND LILLY, LTD.,
PRINTERS,
HATTON WORKS, 113–115, FARRINGDON ROAD,
AND 20–22, ST. BRIDE STREET, E.C.

WELLCOME INSTITUTE
LIBRARY
Coll. welTROmec
Call
No. WC750
1900
C55m

To

W. M. HAFFKINE, ESQ., C.I.E., D.SC.,

Director-in-Chief of the Government Plague Research Laboratory, Bombay:

A TRIBUTE OF RESPECT AND ADMIRATION
FOR ONE WHO HAS, BY THE LABOUR OF YEARS,
BEEN THE MEANS OF ROBBING
TWO OF THE MOST DEADLY OF TROPICAL DISEASES
OF HALF THEIR TERRORS
BY HIS DISCOVERY OF VACCINES FOR
CHOLERA AND PLAGUE.

PREFACE.

THE subject of the connection between the prevalence of Mosquitos and the prevalence of Malaria, discussed in the following pages, must come to be regarded, when more fully understood, as of the utmost importance over the greater portion of the earth's surface. Already, in some countries (especially Italy and India), it has attracted a very great deal of attention.

The literature of the subject has, however, been scattered hitherto so widely through so many medical journals and official reports that it has been difficult for anyone to acquire, without a good deal of study and research, a clear knowledge of what has already been ascertained in reference to the matter.

The object of the present work is to supply, in the form of a small cheap handbook, a concise and convenient summary of knowledge on the subject to date.

Written originally for use in India only, and published in Bombay, the work has now been revised so as to render it suitable for a wider circulation.

I regret that I have not been able, owing to my having been transferred to other duties, to treat the ætiology of malaria, from a mosquito stand-point, as fully as I intended; but I venture to hope, nevertheless, that the work (the materials for which have been gathered under some difficulties, during intervals between my official duties), may be of service, as it stands, to many who are interested in Mosquitos and Malaria, but have not the time or the opportunities for referring to the many publications (British, American, and Italian) on the subject.

There are many points connected with the subject which still remain doubtful and require further study; and, before any really useful rules can be formulated for the destruction of the various species of mosquitos which are now known to be capable of communicating malarial fever to man, the details of their biology must be much more fully worked out. One of the first things to be aimed at is the drawing up of maps showing the geographical distribution of those species throughout the world.

So far as India is concerned, I have the permission of Mr. Haffkine to say that any specimens of mosquitos, larvæ, etc., sent for examination to the Plague Research Laboratory, Bombay, and marked "Mosquitos," will be attended to, in the event of my absence, by the staff of the Laboratory; and that the receipt of all specimens, notes of occurrences, or other information bearing upon the subject, will be duly registered in a book kept for the purpose. The record compiled from this book will be ultimately published.

Mosquitos can be conveniently sent for identification in small boxes or bottles, or compressed between folds of dry blotting paper. Cotton wool should not be used. The larvæ should be sent in a 2½ per cent. solution of formalin, but glycerine and water, boric-acid solution, or weak alcohol will do almost equally well; or the larvæ may be sent alive in a corked tube containing some of the water in which they have lived, if sufficient air is allowed them.

Small glass tubes, $1\frac{1}{2}$ inches long, fitted with corks, and carried in a small box, tin case, or larger tube, are most useful for carrying home specimens or sending them by post.

I am much indebted to Major Ross, D.P.H., M.R.C.S., for having kindly communicated to me some valuable information, of which I have made use.

I have also to thank my brother, Mr. Miller Christy, F.L.S., of Chelmsford, and Mr. E. Bertram Smith, of St. Bartholomew's Hospital, who have been good enough to see the work through the press during my absence from England.

If this little work should be the means of interesting fresh observers, thereby inducing them to add to our knowledge of the subject discussed, I shall feel amply repaid for the labour of preparing it.

As knowledge on the subject is advancing very rapidly, I hope that it may be possible to issue, from time to time, further editions, brought up to date.

CUTHBERT CHRISTY.

BOMBAY,
April 1900.

LIST OF PLATES.

FACING PAGE

CHART showing Relation of the Prevalence of Malaria to Rainfall and Rise of Water in Soil 50

PLATE I.—Head of Culex, Male and Female (Magnified) 68

PLATE II.—Culex: its Attitudes when at Rest, its Eggs, and its Nymphæ 70

PLATE III.—Head of Anopheles, Male and Female (Magnified) 72

PLATE IV.—Anopheles: its Attitudes when at Rest, its Eggs, and its Nymphæ . . . 74

PLATE V.—Larvæ of Culex and Anopheles, from various Points of View 76

CONTENTS.

CHAPTER I.

PAGE

Introductory: The Malaria Parasite . . . 1

CHAPTER II.

Ross's Discoveries (1897-8) 7

CHAPTER III.

Ross's Further Discoveries (1898) . . . 18

CHAPTER IV.

Dr. C. W. Daniels' Investigations (1899) 22

CHAPTER V.

The Work of the Italians and Others (1894-99) . 25

CHAPTER VI.

The Natural History of some Mosquitos . . . 30

CHAPTER VII.

Methods of Destruction of Mosquitos . . . 44

CHAPTER VIII.

The Ætiology of Malaria 49

CHAPTER IX.

The Prophylaxis of Malaria 63

Explanation of Plates 67

Index 77

MOSQUITOS AND MALARIA.

CHAPTER I.

INTRODUCTORY: THE MALARIA PARASITE.

Introductory.—During the summer of 1899, it was reported that a syndicate had been formed to buy up part of the Italian Campagna.

The Campagna is a large tract of malarial and almost-deserted country, some 1400 square miles in extent, with the City of Rome occupying practically its centre. The part of this once-fertile and populous district which the syndicate proposed to acquire lies in the triangular piece of territory bounded by the river Tiber to the north and west, and the Arno to the south and east. This portion is now so malarial that the land is almost valueless, cultivation is reduced to a minimum, and the scanty population is sickly in the extreme.

Why, it may be asked, has this tract of land suddenly become saleable?

The reply is that it became suddenly valuable because a most important discovery in the causation of malarial fever had been made.

This discovery was the fact that mosquitos were the active, and probably the only, agents in carrying malarial fever from man to man. A theory to this effect had been suggested as far back as the time of Lancisi, a Roman physician; but, until now, it had never been proved.

This was not all the discovery. It was found that only a particular sort of mosquito could carry the fever; that this sort could easily be recognised in the larval state; and that it bred only in certain pools and marshes.

Hence it became evident that, within the near future, it might be possible to exterminate these fever-carrying mosquitos, and make a district that was previously almost uninhabitable quite healthy.

The whole subject is of such interest and importance to every one, not only in Italy, but in many other parts of the world, that it is intended to give in the following pages a sketch of the steps which led up to this discovery and the possibilities that it opens out before us.

The Malaria Parasite.—The cause of malaria is a microscopic amœboid parasite which lives inside the red corpuscles—not free in the blood stream, like some other blood parasites.

This parasite, discovered by Dr. Laveran in 1880, is, says Dr. Patrick Manson,* a high authority, by far the most important in tropical pathology. Not only does it give rise to grave and fatal fevers, but, in consequence of its debilitating influences, it undermines the health of millions; and, directly and indirectly, it is the principal cause of death in the tropics and sub-tropics.

Zoologically, it is placed among the Sporozoa, and is closely allied to the Coccidiidæ. Many vertebrate animals are affected by similar, though specifically distinct, parasites, which have been shown, by the observations of R. Pfeiffer and of Simond,† to possess a double cycle of life—one form (the intra-corporeal) adapted to the multiplication of the parasite in the original host: the other form (the extra-corporeal) adapted to its transmission to a fresh host.

* *Tropical Diseases,* (1898) p. 1.

† *Ann. de l'Inst. Pasteur.*

There are several varieties of the sporozoon special to man. Each variety passes through certain definite and well-known stages in its development in the blood corpuscle, and gives rise, during its intra-corporeal life, each to its own particular type of fever—quartan or three-day fever, tertian or two-day fever, and remittent or æstivo-autumnal fever.

But to follow out its extra-corporeal life baffled all the ablest and most careful investigators, until the above-mentioned discovery, made recently in India, put the scientific world upon the right track.

The mature parasite occurs in two forms:—

(*a*) Sporocytes, and

(*b*) Gametocytes.

Both these mature forms are intra-corpuscular, although in some cases it may appear otherwise, for the whole of the protoplasm is often assimilated and nothing remains visible but the limiting membrane.

The sporocytes, having reached maturity and completed a process of segmentation, escape from the including corpuscle, which breaks down—the enclosed segments or spores becoming free in the blood stream. A proportion of these spores attach themselves to other blood corpuscles, which they contrive to enter in some unknown way, and thus give rise to another attack of fever. By the action of quinine, these spores are killed and subsequent attacks of fever prevented.

The gametocytes have no function within the body; but, if a drop of the patient's blood containing them be placed upon a slide and watched under the microscope, they will sometimes be seen to throw out long arms or filaments of protoplasm, called "flagella," which wave about energetically. The significance of these bodies was, until recently, a subject of controversy.

The fact that the flagellated bodies did not come into existence until the blood had left the vessels, and was outside the human body, suggested that their function also was outside the body; and.

because the flagella were formed from parasites of large size and apparently mature, it was thought that the flagella were flaggellated spores, or, in other words, that the flagellated bodies constituted the first phase of the extra-corporeal life of the parasite.

Moreover, the fact that the parasite, whilst in the circulation, was enclosed in the blood vessels and was incapable, therefore, of leaving the body by its own efforts, suggested that it might be removed from the circulation by some blood-sucking insect.

In 1894 Dr. Manson expounded the now-famous theory, based also on the above-mentioned changes in the parasite, that this organism requires a suctorial insect for its further development.*

Then it was discovered, by Ross, in India, in 1895,† that, if a mosquito sucked blood containing these gametocytes, they soon began to throw out flagella, these flagella subsequently breaking away and becoming free in the stomach of the insect.

The chain of evidence now seemed complete, and warranted the following hypothesis, put forward by Dr. Manson, the highest authority on the subject at the time‡ :—

"I conjecture that the flagellum enters some cell of the mosquito, and therein, like any gregarine or coccidium, becomes parasitic, growing and sporulating afterwards, just as the non-flagellated plasmodium enters, grows, and sporulates in the human blood corpuscle. The plasmodium, I hold, is an intra-cellular parasite, both outside as well as inside the human body, and that, when outside the human body, it is parasitic in the mosquito. . . .

"I have further conjectured that the continuation and multiplication of the plasmodium outside the human body is secured by the passage of the mosquito-bred plasmodial spore into the larvæ of the same insect. The mosquito generally dies in water, beside the eggs she has deposited. When the eggs are hatched, the young larvæ commonly devour the body of their parent and, consequently, her parasites. Moreover, being very voracious, they eat any organic matter they come across. We can easily understand from this in what way parasites from the mosquito may get access to the mosquito's offspring. On the infected

* "On the Nature and Significance of the Crescentic and Flagellated Bodies in Malarial Blood (*British Medical Journal*, December 8th 1894, p. 1306).

† See *British Medical Journal*, March 28th 1896, p. 775.

‡ *Tropical Diseases*, p. 16.

larvæ becoming mature insects, the plasmodia they have swallowed continue, I conjecture, to develop. These insects, in their turn, infect their larvæ, and so on. Continuation and multiplication of the plasmodium outside the human body is, in this way, secured. Man, I conjecture, may become infected by drinking water contaminated by mosquitos; or (and much more frequently) by inhaling the dust of the mud of dried up mosquito-haunted pools; or in some similar way."

This hypothesis (though partially incorrect) was generally accepted. For some time, little more was heard of mosquitos and malaria, every careful person living in a malarious country believing that the best way to keep clear of malarial fever was for him to avoid drinking bad water and to boil any that he might be obliged to drink.

It is right to add, however, that the mosquito theory had been elaborated previously by King, in America, in 1893.

The reader may be reminded that it has long been recognised that many parasitic animals require for their complete development to live in two "hosts." The common tape-worm, *Tænia solium*, passes its earlier stage in swine, and then goes on, when the swine's flesh containing it is eaten, to its adult stage in human beings. *Trichina spiralis* has a similar history.

There are, also, in the insect world, many examples of insects acting as extra-corporeal, or definitive, hosts—for example, the Blood-worm, *Filaria*, the cause of Elephantiasis, has been proved to divide its life between man and mosquitos. According to Manson, it is conveyed out of the blood system by the mosquito. It then passes directly from the stomach into the tissues of the insect, which was then supposed to lay its eggs and die on the surface of the water, liberating the young filariæ, which again get access to man when he drinks the water.

We know, also, of two important diseases in cattle (namely, Texan Cattle-fever, and Tsetse-fly disease) which are inoculated, the former by the bite of a cattle tick, *Boöphilus bovis*: the latter by the bite of the Tsetse-fly, *Glossina morsitans*.

It will be noticed that, in these two instances, the disease is conveyed directly by the bite of the insect, and does not require the intervention of water, as was supposed in the case of Filariasis, and as was believed, till recently (*vide* Manson's hypothesis), in the case of malaria.

It is very probable that it will be discovered before long that the mosquito is also the active agent in conveying Filariasis from man to man, and that the intervention of water is not required to complete the life-cycle of the *Filaria*.

In 1897, an important advance was made by MacCallum, in America. He showed that the gametocytes are *sexual* forms, male and female—the flagella being, not spores, but *spermatozoa*, which fertilize the female gametocytes after the blood is drawn from the body (by a mosquito, for example). The fertilized female is now called a *zygote*.

In the next chapter, it will be seen how Ross found the zygotes actually living in the tissues of mosquitos.

CHAPTER II.

ROSS'S DISCOVERIES (1897-8).

To Major Ronald Ross, M.R.C.S., late of the Indian Medical Service, more than to any other man, we are indebted for our knowledge of the close connection which exists between Mosquitos and Malaria.

In a report to the Director General of the Indian Medical Service, dated 19th September 1897, Ross described some *peculiar pigmented cells* observed by him, in August 1897, in the stomach-wall of two mosquitos, of a peculiar kind, having dappled wings and boat-shaped eggs, fed upon a patient suffering from malaria, whose blood contained crescents (the gametocytes of remittent fever).

Believing, as he did, that this pigment was malarial pigment (which, owing to certain characteristics, is not easily mistaken for other pigment), he at once anticipated that he had discovered a further stage in the life-history of the parasite of malaria in these insects.

An abstract of the report was published* in England soon after. To it, were appended some remarks by Dr. Manson, Dr. Bland Sutton, and Dr. Thin, on the original specimens, which Ross had sent them for examination.

While Dr. Manson thought that the cells might be the extra-corporeal phase of the parasite of malaria, he considered it possible for them to be, on the other hand, either normal cells of the mosquito, or some parasite in it, quite independent of malaria.

In September 1897, Ross saw the pigment cells again in other mosquitos.† The results of his experiments, up to this point, have been summarized as follows:—

(1.) Out of a large number of mosquitos of many species examined unfed, none contained pigmented cells.

* *British Medical Journal*, December 18th 1897, page 1786.
† *Ibid.*, February 26th 1898.

(2.) Out of a large number of mosquitos, fed on healthy persons, none contained pigmented cells.

(3.) Out of a very large number of brindled mosquitos, fed on patients with crescents, none contained pigmented cells.

(4.) Out of a large number of grey mosquitos, fed on patients with crescents, none contained pigmented cells.

(5.) Out of four dappled-winged mosquitos, fed on a case with crescents, pigmented cells were found in three.

(6.) Out of a considerable number of dappled-winged mosquitos, fed on healthy persons, none contained pigmented cells.

(7.) One grey mosquito, caught feeding on a case of mild tertian malarial fever, contained pigmented cells.

(8.) Out of 34 brown-brindled mosquitos, fed on a case of triple quartan malarial fever, none contained pigmented cells.

These experiments pointed to the following conclusions:—*viz.*, that the pigmented cells were not normal in the mosquito (1); that no mosquito became infected as a result of sucking healthy blood (2, 6); that it was not all mosquitos that became infected after sucking malarial blood (3, 4, 8); and that only the dappled-winged and one grey mosquito became infected after sucking malarial blood (5, 7).

Unfortunately, at this point, Ross's experiments were interrupted for a period of five months.

The fresh light which these new observations threw upon the subject was deemed, however, to be of such extreme importance that, in February 1898, the Government of India placed Major Ross on special duty to prosecute his researches, and gave him the use of a laboratory in Calcutta for that purpose.

But February was not the malarious season of the year, and suitable cases of malaria were not easy to procure. Ross, therefore, decided to carry out his experiments with bird, instead of human, malaria, his idea being that, as the two diseases were practically identical, he might expect to find his pigmented cells in those mosquitos fed on birds with bird-malaria, if his theory that these cells were an extra-corporeal phase of the parasite was right; and that, if, having found them, he was able to infect with bird-malaria other birds, previously healthy, then his theory would be proved.

Labbé*, Koch†, and others have made an exhaustive study of the two commonest forms of malaria parasites in birds, one called the "proteosoma," found commonly in larks and sparrows: the other the "halteridium," found chiefly in pigeons and crows.

In the adult stage, the proteosoma can be distinguished from the halteridium by the fact that the latter does not alter the position of the nucleus of the red blood corpuscle, while the former pushes it to one side (Koch‡). The red corpuscles in birds are, it must not be forgotten, nucleated.

For an account of the development of the bird-malaria parasites, the reader is referred to the work of Koch and Kossel,† and also to the various papers by MacCallum published in America.§

A vast number of careful experiments was carried out by Ross in the Calcutta laboratory. These are described in detail in Ross's Second Report, dated May 21st 1898.‖ It is only necessary here to give a summary of his results.

Having learnt from his previous experiments (5-7) that only one or two species of mosquitos were capable, in all probability, of carrying human malaria, he conjectured that, similarly, only certain species would be able to carry bird-malaria. His next experiments were, therefore, directed to the discovery of the particular species. After many failures, with all the species of mosquitos available, he found that a common species, which he called the "Grey Mosquito" (species then unidentified), was the only one which contained the pigmented cells after having been

* *Recherches Zoologiques et Biologiques sur les Parasites Endoglobulaires du Sang des Vertébrés*, par Alphonse Labbé (Paris, 8vo, 1894.)

† *Zeitschrift für Hygiene und Infectionskrankheiten*, Bd. 32 (Leipzic, 1899).

‡ See *British Medical Journal*, Oct. 14 1899, p. 1039.

§ See *The Journal of Experimental Medicine*, Jan. 7th 1898.

‖ "Report on the Cultivation of Proteosoma, Labbé, in Grey Mosquitos" (see *The Indian Medical Gazette*, vol. xxxiii., No. 12, Dec. 1898).

fed on birds whose blood contained that form of bird-malaria parasite which is called the proteosoma.

In order to prove this more conclusively, a series of experiments was carried out which gave the following result:—

Out of 245 grey mosquitos, fed on birds with proteosoma, 178 (or 72 per cent.) contained pigmented cells.

A large number of other experiments are detailed in Ross's report. They required the dissection and examination of many hundreds of mosquitos. The following may be mentioned:

Grey Mosquitos were fed—

(*a*) On larks, sparrows, and a crow, with mature proteosomata;

(*b*) On larks and a sparrow, with immature proteosomata only;

(*c*) On crows, pigeons, and other birds, with halteridia only.

(*d*) On a man, with crescents.

(*e*) On a case of immature tertian parasites; and

(*f*) On healthy sparrows.

Only the insects fed on group (*a*) contained pigment cells.

To show still further the restricted association between proteosomata in the birds and the pigment cells in the grey mosquito, the following experiment, one of many, may be mentioned:—

Thirty mosquitos, caught in the larval stage, all in the same drain and hatched out in the same breeding bottle, were fed as follows:

(*a*) Ten on a sparrow whose blood contained numerous proteosomata. When examined, these ten contained 1,009 pigment cells, or an average of 101 each.

(*b*) Ten on a sparrow with a moderate number of proteosomata. When examined, these contained 292 pigment cells, or an average of 29 each.

(*c*) Ten on a sparrow with no proteosomata. When examined, these contained no pigment cells.

It is probable that the grey mosquito mentioned in his early experiment No. 7 had fed upon a bird infected with proteosoma or halteridium previous to its being fed upon the case of mild tertian.

Now as to the *technique* of these experiments:—In his report, Ross says: Mosquitos are obtained by catching the larvæ in the pots of water, drains, or puddles in which they live. They are then placed in wide-mouthed glass vessels, covered with muslin, until they hatch out into the perfect insect.

The vessel is then opened under an ordinary mosquito net under which has also been placed the subject for experiment—a bird in a cage. In the morning, the mosquitos, gorged with blood, are caught in test tubes, in which they are kept and, when wanted, are killed by chloroform or tobacco smoke. The tubes should contain a few drops of water for the inmates to drink and lay their eggs in, and should be changed for clean tubes every morning.

Grey mosquitos fed at night remain gorged and asleep all the following day and night. Towards the end of the second day the stomach begins to "clear" (that is, the meal has been partly digested and partly evacuated), leaving the organ partially empty. The eggs are usually laid on the third day, after which the insect generally dies if it has not been fed again. To keep them alive for twelve days or so, they must be fed every other day.

A mosquito, Ross says, is dissected for examination of the stomach in this manner:—A needle is passed through the thorax; the legs and wings are pulled off. Holding the needle in the left hand, the insect is then lowered into a drop of water, salt solution, or weak formalin, placed on a glass slide. The last two segments are partially separated and held down upon the slide by another needle. The body is then moved away in such a manner that, if done skilfully, the alimentary and generative organs will remain on the slide attached to the last two segments of the tail.

The alimentary canal consists of an œsophagus, stomach, and a short straight intestine leading to the anus and containing six heart-shaped glands near the rectum. Five long tubes, the malpighian tubes, open into the stomach at its junction with the intestine.

The stomach wall consists, beginning from the inside, firstly, of several layers of large cells, which contain nucleus and nucleolus; then a delicate homogeneous membrane, which Ross calls "the outer homogeneous coat"; then the muscular coat, consisting of bands of muscular fibres crossing each other at right angles and obliquely; and, lastly, the ramifications of the air vessels externally. For a further description of the anatomy, Ross's report must be consulted.

Ross thus describes the development of the pigmented cell:—

Taking an insect fed, we will say, during the previous night upon a healthy sparrow, we dissect it in the manner described above.

The stomach, full of blood, with the œsophagus, intestine, malpighian tubes, and ovaries attached, lies before us on a glass slide.

With the point of a needle, we open the side of the organ, and the contained blood runs out freely into the water of dissection.

If, now, a cover glass is applied, we can easily examine, with the highest powers, the stomach tissues or their contents, or, if we wish, we can wash away the latter by irrigation with water or weak stains and study the tissues alone.

In the case of the mosquito fed on a healthy sparrow, we shall find that the contents consist of red and white corpuscles crowded together, and a little remaining serum densely coloured with exuded hæmoglobin. On examining the tissues we find no trace of the characteristic pigment of proteosoma or halteridium.

Taking, however, an insect fed at the same time on blood containing mature proteosomata, we shall find, in the contents, besides the condition of blood just described, not only traces of these parasites, but entire ones, still enclosed in the corpuscles, or lying free in the yellow serum. In some of these, the pigment is still oscillating.

On the *second* day, the blood in the cavity of the stomach of the insect fed on healthy blood is still further disintegrated. The red corpuscles and leucocytes have, as a rule, disappeared, and a fairly-homogeneous reddish-black mass of multitudes of granules, with brownian movement, remains; or the stomach may, by this time, have poured its contents into the intestine; which, in its turn, may have evacuated them, in which case the insect is ready to feed again.

But if the insect is one which has fed on blood containing mature proteosomata, we shall still find some traces of these parasites in the granular mass of disintegrated blood in the stomach, in the shape of (*a*) small clusters of pigment, (*b*) scattered pigment granules, or (*c*) pigment contained in a yellowish hyaline cell, the remains of the entire dead parasite.

In the tissues, something abnormal is at once noted:—The external muscular and homogeneous coats of the stomach are found to be studded with small clusters of pigment, identical in appearance with the characteristic pigment of proteosoma. These clusters of pigment constitute the youngest form of the pigmented cells, but their cellular outline has not yet become apparent. They lie invariably either in the homogeneous coat, or still further outwards, between the strands of muscular fibre, in the manner with which we are familiar in the case of *Trichina* embryos. They have never, as yet, been found lying in or amongst the innermost layer of cells or in the cavity of the stomach itself.

During the morning of the second day after feeding, when the pigmented cells first appear, there is considerable variety amongst them. The earliest form is a mere cluster of about 20 grains of pigment. A little later, these 20 grains are seen to be enclosed by a faint oval outline. In another and probably a later form still, we find, interspersed amongst the pigment, distinct vacuoles and refractive granules. These varieties have three things in common—their pigment, their oval outline, and (approximately) their size. Often, all the pigment cells in one mosquito belong to the same variety. As the day advances, the cells become larger, the vacuoles and granules become more numerous, the pigment tends to collect round one or two of the larger vacuoles, and the outline of the cells becomes more distinct.

It will be remembered that cells similar to these were found on the second day in mosquitos fed exclusively on human blood containing crescents (see experiment 5, p. 8).

On the *third* day, says Ross, the pigment cells are larger and their outline is rounder. They are now more uniform in appearance and belong distinctly to two varieties only—one containing granules and some large vacuoles: the other, clear and hyaline, with some faint vacuoles towards the centre. In the former, the granules are more numerous and closely packed together than on the previous day, the vacuoles are larger, and the pigment (the particles of which are less than on the previous day) tends to accumulate round one or two of the larger vacuoles in both varieties.

In some mosquitos, nearly all the cells belong either to one or the other variety; but, in others, the two varieties are found side by side. As the third day advances, the pigment tends to decrease in amount; and, in some of the largest cells, a few bright refractive points begin to appear, scattered through the granular plasma.

On the *fourth* day, if the insect has survived without re-feeding, the pigment cells will scarcely exceed in size those observed on the third day; but, if it has been fed again, they are much larger, and the granular and hyaline varieties can still be clearly differentiated. The pigment may still oscillate within a small area, but is now greatly reduced in amount. In some, the pigment has disappeared, while the bright refractive points referred to have increased in number and size. In the granular variety, the number of granules and vacuoles increases with the growth. At this stage, the cells protrude from the external wall of the stomach, like warts on a finger—not into the cavity of the stomach, but into the general body-cavity (the cœlom).

If the mosquito has been re-fed, on the second day after first feeding, on the original bird or on one infected with mature proteosomata, a fresh generation of young pigment cells, similar to those observed on the second day, will now be seen.

From this point, then, the parasitic nature of these bodies became obvious. Ross assumed that they were coccidia, and therefore henceforth called them proteosoma-coccidia.

On the *fifth* day, he says, the coccidia continue to grow and protrude into the cœlom, but the difference between the granular and the hyaline cells has become less marked; the pigment has disappeared; and each coccidium now consists of a capsule containing a more or less granular and vacuolated substance studded with numerous small bright points.

On the *sixth* day, the coccidium may have reached a growth of 60 or even 70μ, easily visible with a magnifying glass.

These changes can be hastened or retarded by raising or lowering the temperature. Instead of one week, they can be prolonged, if desired, to two weeks or more.*

Beyond this point, Ross observed no further growth in the coccidia, although he examined coccidium-infected mosquitos kept alive till the twelfth day.

* Some excellent diagrams, showing the appearance of the coccidia at different stages, are given in Ross's report.

If mosquitos of this stage, says Ross, be dissected in plain water, the coccidia will be seen bursting in all directions, pouring out their contents slowly into the surrounding fluid, and leaving behind a collapsed and wrinkled capsule still attached to the stomach wall. In some of these collapsed capsules can be seen a number of black sausage-shaped bodies. He describes, also, a peculiar striated appearance which he noticed in many mature coccidia between the 6th and 12th days, the striations appearing to radiate from one or two of the bright points previously mentioned as appearing on the third day.

Further investigation, he says, is needed as to the significance of the striation and of the black bodies, but he ventures the following hypothesis:—

Since no further growth of the coccidia has been noticed, we may expect that they have become ripe for sporulation; and, since they are in a closed cavity (namely, the body-cavity of the host), there appears to be no means by which they can escape from that host during its life, to undergo sporulation in external nature, just as there appeared to be no way in which the malarial parasite could escape from the human body for the same purpose. It would appear, therefore, that sporulation must occur either (*a*) in the living insect, after twelve days, or (*b*) sometime after the insect's death. The first would point to a completion of the life-cycle by a direct infection of men and birds by the coccidium spores in the mosquito: the second, to a more circuitous infection, perhaps by a second generation living free in water. This latter would coincide with Manson's suggestion that malaria may be conveyed by drinking water which has been contaminated by mosquitos.

That the young forms of coccidia of the second day are directly derived from the ingested proteosomata is proved beyond doubt by the following facts:—

(1) That they contain the characteristic pigment of proteosoma;

(2) That they are to be found in a large percentage of grey mosquitos fed on blood containing proteosomata, and are never observed in the insect fed otherwise; and

(3) That they occur always on the second day after the insect is fed on blood containing mature proteosomata, and only on the second day after such feeding: not before.

No sign of movement has been observed in the coccidia. The older coccidia have never been seen in grey mosquitos except when fed on birds infected with proteosoma.

Whether the coccidia are intra-cellular in their younger stages (that is, originally contained in a cell of the mosquito) remains doubtful, and this point will probably not be cleared up until the gap in the continuity of development of the coccidium from the flagellum, or from the mature parasite which has been penetrated by a flagellum soon after reaching the stomach of the mosquito, has been bridged over.*

In concluding his report, Ross points out that the cultivability of proteosoma becomes a fact of great practical importance, implying, as it does, the ultimate solution of the problem, which has so long puzzled investigators, of the life history of the parasites of malaria outside the human body.

It remained, however, to discover—

(*a*) The sporulation of the proteosoma-coccidia and further stages; and

(*b*) The appropriate second hosts for the different species of malaria parasites.

We shall see presently how near Ross himself was to the discovery of (*a*).

It should now be noted carefully that what Ross originally called "pigmented cells" and "coccidia" were really the fertilized female gametocytes (or zygotes) of the parasites (see p. 6). This point was early noted by Manson.

* See MacCallum: "On the Flagellate Form of the Malarial Parasite" *Lancet* November 13th 1897, p. 1240).

CHAPTER III.

Ross's Further Discoveries (1898).

In October 1898, Major Ross handed to the Director-General of the Indian Medical Service a Third Report,* dealing, with some further researches of the utmost importance on the development of proteosoma-coccidia.

He takes up the subject again at the point at which his former report left it—namely, the appearance, in the mature proteosoma-coccidium, after the seventh day, of what he now considers to be reproductive elements: namely, (*a*) a large number of delicate thread-like bodies (the striations mentioned as radiating from certain refractile particles), and (*b*) a smaller number of large black sausage-shaped bodies, which he now considers to be spores.

The minute thread-like bodies taper, he says, to each extremity, and contain vacuoles and chromatin granules, in their middle. They are closely packed in the capsule of the mother coccidium. No certain indications of movement in them have been noticed; but, as they are invisible in water, and only became visible when stained, or when shrivelled by the salt of the solution in which they are examined, it may be doubted if they have been seen alive. This is, probably, the reason why they were mentioned in his previous report only as striations.

The large black spores are cylindrical, closed at the ends, and are straight, curved, sigmoid, or variously twisted.

"I have never [he says] observed both the thread-like elements and the black spores in the same coccidium."

Overshadowed by the interest attached to the thread-like bodies, the large black spores seem to him to be of little importance.

* "Infection of Birds with Proteosoma by the Bites of Mosquitos" (see *The Indian Medical Gazette*, vol. xxxiv., Jan. 1899).

On the eighth or ninth day, shortly after the coccidia have matured and produced their reproductive elements, they burst *in situ* in the living insect, and pour those elements into the general cavity of the body. They are swept away by the so-called blood or circulating juices and are distributed throughout the tissues of the mosquito. If we kill a mosquito ten days after it has been fed on a sparrow with proteosoma, we shall most certainly find large numbers of the thread-like bodies in the juices of the head and thorax, and also some of the black spores in almost all the muscular and connective tissues of the body.

While examining these thread-like elements in the blood of mosquitos, says Ross:

"I observed that they were frequently to be found collected within the cells of some gland in the thorax, the nature of which was unknown to me at the time. This eventually proved to be the *salivary* or poison gland of the mosquito."

This organ, which is closely similar to the well-known salivary gland of other insects, is situated in the neck, or anterior part, of the thorax of the mosquito, and consists of a number of lobes. Each lobe is made up of numerous large cells clustered round a central duct. The main effluent duct runs up the under-surface of the head; enters the base of the central unpaired stylet of the proboscis (Pl. III., fig. 3); traverses the whole length of it; and opens, at its extremity, in such a manner that the secretion of the gland must be poured into the tissues in the manner of a hypodermic needle. The use of the secretion is probably to produce an influx of blood to the spot.

It is in this gland that the thread-like reproductive elements of the proteosoma-coccidium are found accumulated in large numbers, either floating singly in the cavity of the grape-like cells or crowded together in them in hundreds. It is impossible to mistake their identity or to err, Ross thinks, in the interpretation of these observations. The existence of this gland affords the minute thread-like bodies (which clearly have the significance now of reproductive elements) the opportunity, so to speak, of returning to a warm-blooded host, where, if that host be a bird of an amenable species, they doubtless originate an infection of proteosoma, thus completing the life-cycle of the parasite.

All that was required to obtain complete proof of this theory was actually to infect healthy birds in the manner suggested.

This was accomplished.

Four sparrows and one weaver bird, whose blood on several examinations had been found to be entirely free from proteosoma, were subjected nightly to the bites of numerous grey mosquitos, fed, more than a week previously, on a sparrow whose blood contained proteosomata. Ten days afterwards, these birds were found to have become infected with swarms of the parasites. All of them died very soon, and in each one the liver and spleen were found to be profusely charged with the characteristic black pigment of proteosoma. This was in July 1898.

Out of twenty-eight healthy sparrows experimented on in this way, twenty-two (or 79 per cent.) became infected in from five to eight days. In all the birds in which the parasites appeared after the experiment the invasion presented such constant and unmistakable characters that there was absolutely no room for doubt that the infection was due to the mosquitos. And, owing to the fact that the proteosoma, the halteridium, and other malaria parasites of birds, so closely resemble the malaria parasite of man, there seemed no reason to doubt that man is infected in the same way; but this remained to be proved.

" The members [parasites] of this group, says Koch, show such remarkable analogies in the processes of their development that the laws which govern the development of one variety may, *mutatis mutandis*, safely be assumed to hold good in that of the others. For instance, if halteridium [of pigeons and crows] forms 'vermiform bodies' at one stage of its growth, it is tolerably certain that the human malaria parasite will be shown to do likewise."*

* *British Medical Journal*, Oct. 14th 1899, p. 1039.

Ross was not able, whilst working in India, to identify properly the species of mosquito with which he was experimenting; but it has since been shown that what he called the "Grey" and "Brindled Mosquitos" belong to the genus Culex; while his "Dapple-winged Mosquitos" belong to the genus Anopheles.

CHAPTER IV.

Dr. C. W. Daniels' Investigations (1899).

In scientific work, before any new observation is accredited, it must be confirmed and accepted by men of recognised scientific standing.

In December 1898, therefore, the Royal Society, in conjunction with the Colonial Office, sent out Dr. C. W. Daniels, a member of the Malaria Committee of the Society, to Calcutta, for the purpose of confirming the results of Major Ross's experiments.

According to his report, Dr. Daniels examined all Ross's preparations, carried out many of his experiments afresh, initiating others where there seemed a weak link in the chain of evidence, and confirmed the whole of his work in all its details.*

The black tubular spore-like bodies (the sausage-shaped bodies of Ross) seem to have particularly arrested his attention.

"Mention has been made [he says†] of the differentiation of the coccidia (previous to the formation of the germinal threads) according to the appearance of their contents, into clear and granular; the evolution of the latter into the coccidia containing germinal threads can be traced day by day. This differentiation was clearly visible in my series.

"In a minority of the coccidia, and in most infected mosquitos, when the germinal threads are mature, certain black tubular bodies are to be found in cysts with otherwise clear contents. . . . Most of these infected mosquitos contained some coccidia with black tubular spore-like bodies, though in a few insects all the cysts contained germinal threads only. In some cysts the black spores were numerous and occupied the entire cyst; in other cysts there were only a few.

"In most instances germinal threads were not found in the black spore-bearing cysts, but there were a few such cysts in

* Dr. Danie's report will be found in the *Proceedings of the Royal Society* (vol. 64, pp. 443-454), and also in the *Journal of Tropical Medicine* (July 1899, p. 388).

† Report, pp. 450-451.

which it was doubtful whether the germinal threads were present or not, or whether the appearance arose from overlying threads which had escaped from a neighbouring capsule.

"These black spores are very resistant. I have seen some which have been kept in water for months by Ross, and which had undergone no visible change. They withstand irrigation with *liquor potassæ*.

"When the cysts are ruptured, the black spores are to be found all over the body of the mosquito, but not included in cells. They do not seem to accumulate in any particular organ.

"The most plausible view of the nature of these black spores seems to be that they are 'resting spores' and that through them, by another cycle, the proteosoma can be propagated in conditions unfavourable for direct propagation by mosquito insertion into a warm-blooded animal.

"If this be the case, three courses suggest themselves:—

"(*a*) From the black spores may arise bodies capable of non-parasitic life (and, possibly, of reproduction), which, at certain stages of their existence, and in certain conditions, on introduction into a warm-blooded host by inhalation, through drinking water, or even by injection by a mosquito or other blood-sucker, in transferring them from the medium in which they live, may resume parasitic habits.

"(*b*) That they may be ingested by mosquito larvæ, and in them undergo such development as will result in the formation of germinal threads in the adult mosquito, which, in turn, may be injected into the appropriate bird.

"(*c*) That they may, if swallowed or inhaled by an appropriate warm-blooded host, so develop as to reach the circulation and pass into the sporulating phase.

"Such experiments as have been made on this subject are inconclusive, and it is obvious that, until the nature of these black spores is determined, we cannot exclude, even for proteosoma of sparrows, the possibility of any one of the many alternate channels of infection. Intervention of the mosquito intermediate host may be only an occasional requirement.

"Still less are we justified in concluding that malaria in man can only be acquired through, and directly from, the mosquito; or in devoting our attention exclusively to that channel."

Dr. Daniels, with the cautiousness of a man of science, wished to draw attention to the fact that, although Ross's discoveries have put observers on the high road to proving that the mosquito conveys malarial fever from man to man, they do not prove that it is the *only* way in which the fever can be carried.

Daniels wrote his report over a year ago. Since he did so, the fact that mosquitos can and do infect human beings with malaria seems to have been proved to the satisfaction of all authorities; but, as far as I am aware, our knowledge of the function of the black spores remains where it stood at the time of his report, in spite of careful study by Koch and others.

For this reason, it is now generally believed that they are some degenerative or abortive form of cell, because they are so resistant to external influences, because they do not occur in every coccidium-infected mosquito, because they occur in coccidia without the thread-like bodies and which are otherwise hyaline, because drinking water containing them has failed repeatedly to produce malaria, because all investigations have failed to discover them in the larvæ, or in Anopheles born from larvæ fed upon insects containing them, and for many other reasons deduced from our more complete knowledge of mosquitos, enabling us to explain almost all the many facts and beliefs of ages past in connection with malaria.

Nevertheless it should be borne in mind that these black bodies still may turn out to be "rest-spores," or to have some other definite function.

CHAPTER V.

THE WORK OF THE ITALIANS AND OTHERS (1894-9).

Malarial fevers are such a curse to Italy that the Italians have every possible reason for leaving no stone unturned which may possibly lead them to a solution of the difficult problem of how to lessen the scourge. Many remarkable and interesting experiments are detailed in the publications of Grassi, Celli, Bastianelli, Bignami, Casagrandi, Santori, and others, which have appeared during the past eighteen months.

Whilst Ross was working on proteosoma in Calcutta, the probable connection of mosquitos and malaria was being studied by the distinguished Italian malariologist Bignami.

Bignami's first experiments were made in 1894, when a number of mosquitos, of several species, were brought from a malarious district and set free in a suitable room in Rome, in which slept a man who had never previously had malaria. The result was negative, as also were the results of several similar experiments during the succeeding three years.*

In the summer of 1898, after Ross's first work on Protoseoma was announced by Manson,† Grassi, a well-known Italian naturalist, made an exhaustive study of the mosquitos occurring in different parts of Italy. He found that, in all the malarial zones, certain mosquitos were to be found, and that, in every spot where members of this genus were found, malaria was prevalent. This fact, in conjunction with Ross's papers, showing that special mosquitos were needed as the hosts of the parasites, at once suggested to Bignami the course which he had to take.

The same man who had voluntarily submitted himself for experiment before, and whose history Bignami publishes‡ to show

* See *Lancet*, Nov. 21st 1896, p. 1444.
† See *British Medical Journal*, June 18th 1898.
‡ *Lancet*, Dec. 3rd and 10th 1898.

that he had never been exposed to the chances of malarial infection, again submitted himself to experiments. Guided by Grassi's information, certain mosquitos were brought from Maccarese, where fever prevailed. These were identified by Grassi as being identical with species which he had found in all malarial zones.

Although some of these mosquitos proved ultimately to be the human malaria-bearing species, it could not, of course, be ascertained whether they had previously fed on a person whose blood contained the mature parasite; but this was more than likely, for the neighbourhood whence they came was very malarial.

These mosquitos were set free, in Rome, in a suitable room, in which the man lived and slept. Moreover, in the district of Rome in which the experiment was carried out, there had not been a case of malarial fever caught in that district within the memory of medical men, the centre of Rome being absolutely free from fever.

For some time after the minimum period, the experiment did not succeed, but ultimately (on November 1st 1898) it was successful, and the subject of the experiment began to suffer from symptoms of fever. His blood was examined and the parasites of what is called summer-autumn fever, identical with the type of fever which prevailed at Maccarese, were found.

Thus Bignami first succeeded in getting positive evidence of the direct inoculation of malaria by mosquito bites.

This result has been amply confirmed by further experiments by Bignami, Bastianelli, and Grassi.

It has now been conclusively shown, therefore, that if mosquitos belonging to the genus Anopheles (which includes Ross's "Dapple-winged Mosquito") be made to bite a man suffering from malarial fever, and be then kept at a proper temperature (30deg. C.) for the requisite number of days, to allow the sporozoites to develop in the veneno-salivary gland, and if they be then made to bite a healthy man who is free from malarial infection—that this man will, after the regular incubation period, develop malaria. And it is important to note that the parasite so conveyed from man to man retains its specific type.

It further results from the experiments in question that a very few bites are sufficient to convey an attack of fever—a single one probably sufficing. What is important is the species of mosquito and the stage of development of the parasite when it is ingested by the mosquito.

These experiments have shown also that the development of the parasite of human malaria in the body of Anopheles is identical with the development of proteosoma in the "Grey Mosquito."

It seemed at one time quite possible that each of the main types of the human malaria parasite (each of which gives rise to a distinct clinical type of fever) might be found to require a particular species of Anopheles to propagate it, but recent observations by the Italians partly disprove this.

Ross found* also that, in certain barracks at Sierra Leone, three types of malarial fever were observable among the troops, but only one species of Anopheles could be found in the buildings. Hence he inferred that this one species conveyed all three types; and, as a matter of fact, the zygotes (the coccidia, or pigment cells) of both quartan and tertian fever were identified in the insects. He says that the insects were caught engorged with blood, whilst resting on the walls; were kept two or three days; that they were then examined; and that the young zygotes of quartan and tertian fever could be recognised at once on inspection of their pigment—that of the quartan zygotes being coarse, of a dark-brown colour, and comparatively scanty: that of tertian being very copious, fine, and of a light-brown colour. It was not possible to tell, by inspection, from which species of parasite the zygotoblasts (thread-like bodies) had been derived.

Smith and Kilborne have shown† that the hæmatozoon which

* See *British Medical Journal*, September 16th 1899, p. 746.

† *Investigations into the Nature, Causation, and Prevention of Texas or Southern-Cross Fever*, by T. Smith and F. L. Kilborne (Washington, 1893)

causes Texan Cattle-fever is transmitted from a tick, which is its temporary extra-corporeal host, to a second generation of ticks, by which it is again conveyed to cattle. The resemblance between the hæmatozoon of Texan Cattle-fever and the human malaria parasite is so considerable that the proof that the one was conveyed by an insect was considered by the Italians almost a proof—even before it had been actually demonstrated—that human malaria must be similarly conveyed, and rendered it necessary to investigate whether in Anopheles also, the parasite is transmitted from parent to offspring.

The Italian observers, therefore, made a diligent examination of this question. They cultivated the larvæ of Anopheles taken from near houses that were infected with malaria, and, when the new generation of winged insects was developed, they allowed them to bite healthy people. These experiments turned out negatively.

At the hospital of Santo Spirito, a person who had never had malaria exposed himself voluntarily to the bites of new-born Anopheles. He was bitten for twenty days by numerous insects of this genus, which were developed in a room in the hospital. He continued, nevertheless, to enjoy good health.

In the laboratory of comparative anatomy, Professor Grassi and five other persons belonging to the laboratory exposed themselves to the bites of numerous Anopheles which had been developed in the laboratory from larvæ or nymphæ taken at many places in the Campagna, often from near dwellings in which malaria had run riot. These persons were bitten daily; yet not one of them became infected with malaria.

So far, therefore, the results of all these experiments have been negative; and, up to the present time, only those Anopheles that are known to have bitten human beings suffering from malaria have been shown to be capable of propagating the disease.

After an attack of malarial fever, especially in cases in which the treatment has been faulty, the parasites may retire from the general circulation and, it is believed, pass what is called their "latent phase" in the spleen, bone marrow, or some other of the deeper organs of the body. There they may remain quiescent for many months, until some devitalising influence, such as a chill or prolonged exposure to the sun, brings them once more into the peripheral circulation, where they sporulate afresh, giving rise to a recurrence of the fever without the intervention of any mosquitos.

After the foregoing, further proof of the fact that mosquitos are capable of conveying malaria—hitherto a theory merely—seems unnecessary.

Professor A. Celli, of Rome, summarises the subject concisely as follows* :—

"Man and mosquitos are the sources of malarial infection, which circulates, so to speak, from man to mosquito and from mosquito to man, and so on. In this circulation of the contagion, the presence of malarial man is indispensable, inasmuch as, down to the present time, the hereditary transmission of malaria from mosquito to mosquito has not been demonstrated experimentally or morphologically, nor have resisting parasitic forms been found in the environment external to the body of the mosquitos. Malaria is, therefore, a typical contagious disease.

"Where there is malaria, mosquitos abound; but malaria does not exist in every place where mosquitos abound, which is explained by the fact that, in malarious regions, particular species of mosquitos live. Those capable of lodging the specific parasites and of infecting man, appertain to the genus Anopheles.

"All the four species (*A. claviger* or *maculipennis*, *A. bifurcatus*, *A. superpictus*, and *A. pseudopictus*) of this genus which exist in Italy are injurious. It is not probable that the species of Culex, or other blood-sucking insects which are found in malarious places, can also transmit malaria.

"And, since (as far as is at present definitely known) the specific germs external to man live, not in the soil, but in the body of the mosquito, it follows that malaria can no longer be cited as a classic example of a disease of the soil. . . . The same may be said of water. It may be, and in fact is, the habitat of the eggs, larvæ, and nymphæ of the mosquitos which eventually become malarigenous. Therefore soil and water pass into the number of indirect epidemic causes.

* *British Medical Journal*, Feb. 10 1900, p. 301.

CHAPTER VI.

THE NATURAL HISTORY OF SOME MOSQUITOS.

We come now to the study of the Life-History of the Mosquitos themselves, which can be most conveniently discussed under various sub-headings.

General.—The mosquito undergoes, as most of us know, four stages of development. The first stage (that of the egg) is passed on the water; the second (the larva stage) is passed in the water; the third (the pupa or nympha stage) is also passed in the water; the fourth stage (that of the adult insect) is passed chiefly on the wing.

Beyond this, the natural history of mosquitos is, to a large extent, unknown. The chief aim in publishing this work is to stimulate the interest and to enlist the energies of naturalists, medical men, and others throughout the world.

The mere collection and classification of the many different species of mosquitos found in various parts of the world is by no means sufficient from a medical point of view. Far too much attention has recently been paid to it, to the exclusion of more useful investigations.

What is required is a more intimate knowledge of the *life-history* of the mosquito, and of Anopheles, our enemy, in particular, in all its four stages. Some of the chief points to which observers should devote their attention are the following:—The distribution of the different species; when and where they lay their eggs; the conditions of temperature, etc., which modify the length of time of hatching of those eggs; the amount of cold or of desiccation that they can withstand; the distinctive characters of the larvæ of each species; the food they each feed upon; the character of the localities in which they are found; the distance from human habitations; the number of broods in the year produced by each species; the duration of life of the mature insects; and the time of day or night at which they feed.

Collection.—For a description of how to collect mosquitos for the cabinet, and of the apparatus which is necessary, those interested may refer to a pamphlet on the subject issued by the Natural History Department of the British Museum, South Kensington.*

Classification.—Our knowledge of the different species of mosquitos comprised in the Family Culicidæ is, as yet, very limited, and little has been done to classify them properly.

The European members of the family can, however, be divided, according to Ficalbi, into three genera, based on the following characters:—

The first, *Anopheles* (from the Greek, meaning hurtful) has the palpi in both sexes about the same length as the proboscis (Pl. III.);

The second, *Culex* (to which Ross's "Grey Mosquito" belongs), has the palpi about the same length as the proboscis in the male only, but in the female much shorter (Pl. I.);

The third, *Aedes*, has the palpi in both sexes much shorter than the proboscis.

It matters little, however, what classification is used, for we are chiefly interested in the two genera Culex and Anopheles, seeing that these two genera comprise almost the whole of the family of Culicidæ.

Culex is of world-wide distribution, and Anopheles has to be differentiated from it. The palpi, upon which entomologists have based the above classification, are organs growing from the front of the head and seem, in most cases, to have much the same function as the antennæ, or feelers.

* This pamphlet is reprinted in the *Journal of Tropical Medicine* (January 1899, p. 170).

The Genus Anopheles.—Fortunately, Anopheles can easily be recognised and distinguished at a glance from mosquitos belonging to the much more common genus Culex, by its attitude whilst resting on the wall (Pl. IV., fig. 1), as was pointed out by the members of the Sierra Leone Mosquito Expedition of 1899.

In this situation, it looks, at a short distance, not unlike a thorn sticking in the wall, pointing upwards at an angle of 45 or 50 degrees.

The proboscis, with the head, points in the same direction as the axis of the body. It is thick and noticeable, owing to the palpi being held close to it (Pl. III., figs. 1, 2). The legs are long and exceedingly slender; the body is slender; and the wings are small and light-coloured, except for four conspicuous brown spots on their anterior margins (Pl. IV., figs. 2, 3, 5).

From its position on the wall alone, Anopheles can easily be recognised (so far as is yet known).

Anopheles is a fragile-looking insect, very active and difficult to see on the wing, and able to pass easily through the meshes of ordinary mosquito-netting. Its appearance has been likened to that of a miniature humming-bird moth. Add to this its alleged muteness and its painless bite, and it is easy to understand how it is that a careless observer may assert that a certain district, although known to be malarious, is free from mosquitos.

The different species belonging to the genus vary a good deal in colour and markings. Some are of a light fawn colour; some a dark-greenish black. Some species have two spots on the wing, whilst others have three, and one at least has none.

The Genus Culex.—On the other hand, Culex, the common mosquito, rests upon the wall with its body either parallel to it or pointing in towards it at the tail end, as it were (Pl. II. fig 1). It has a distinctly hump-backed appearance; its proboscis is slightly curved and carried at a considerable angle with the body; and its head is at a lower level than the thorax.

The insects usually rest with the body well away from the wall; but, after feeding, they may crouch flat against it. The hindermost pair of legs is generally to be seen curved up over its back. This is not the case (as already observed) with Anopheles, which rests stilt-like, unless disturbed, when it at once puts its legs out behind.

The different species vary greatly in markings, some species having the legs and proboscis ringed black and white, while in others they are plain. In some, the wings are beautifully marked; but, in the commoner species, they are plain brown, grey, or greenish-black.

The Ova of Anopheles.—If the débris, floating on the surface of the water in which some species of Anopheles is breeding, be examined with a lens, the tiny black rod-shaped eggs will be seen, either singly, or attached to floating objects, or collected together in characteristic little patterns (Pl. IV., fig. 6). Often they are attached to some fixture at the edge of the water. They require about twenty-four hours or more to hatch out, the time varying according to the temperature.

The Ova of Culex.—No lens is required to find the eggs of Culex (at least of some species), for they are massed together vertically, in black boat-shaped collections of a hundred or more, each mass being an eighth of an inch, or even nearly a quarter of an inch, in length (Pl. II., figs. 7, 8). The eggs require about the same time as those of Anopheles to hatch out, all those in one boat doing so nearly simultaneously.

The Larvæ of Anopheles.—The larvæ of Culex and Anopheles also have some very obvious differences between them.

The larva of Anopheles floats horizontally at the surface of the water, like a tiny piece of stick (Pl. V., fig. 4), and this position seems never to have varied. If a specimen be placed in a drop of water upon a glass slide and examined under the microscope, using a low power or even a good hand-lens, it will be seen that the breathing tubes, or tracheæ, which run down the length of the body, one on each side of the middle line, and can be seen throbbing, end in the last segment, in two round apertures (Pl. V., figs. 2, 3).* Hence the necessity for the larvæ to come close to the surface of the water in order to breathe.

Looking down upon the larva in a tumbler, it will be noted that the head is black and narrower than the thorax (Pl. V., fig. 1). Looking at it from below the level of the water in the tumbler, it will be seen that the head is carried in the same plane as the body, just as the proboscis in the adult insect is carried. When at the edge of the tumbler, it nearly always has its head towards the centre (Pl. IV., fig. 11); and, if disturbed, it swims across the surface backwards, with a series of vigorous jerks. If persistently disturbed, it becomes exhausted, and can be pushed about with a penholder as if it were dead.

As a rule, the larvæ of Anopheles are to be found at the surface. They feed chiefly at the surface; but, if the puddle in which they are living is only a few inches deep, they can be watched slowly sinking, one by one, to the bottom, to feed amongst the mud or stones, and then, after a minute or less, jerking themselves backwards up to the surface again, by alternately curving the tail round to the head first on one side then on the other. Sometimes (depending, possibly, upon the clearness of the water) they will disappear instantly from the surface in a body when disturbed or when a dark shadow falls upon them; and this they do so quickly that it is difficult to catch them. In these cases, they are likely to be mistaken for the larvæ of Culex.

Owing to their bodies being somewhat transparent, they vary in colour according to the food upon which they are feeding. If it is algæ alone, they are dark; but, if the water is muddy and algæ scarce, they are very light coloured, except the head, which seems to be always black.

* I have found it convenient to add a little acid to the water on the slide, during examination, in order to quiet the struggles of the specimen.

The Larvæ of Culex.—The distinctive feature of the larva of Culex is that it hangs head downwards, from the surface of the water, breathing through a prolongation of its tail (Pl. V., fig. 8).

If examined on a glass slide, under a low power of the microscope, it will be seen that the breathing-tubes are prolonged from the surface of the body, near the tail, into a chamber of considerable length, in which they dilate in a fusiform manner, and terminate at the end of it in small stigmatic orifices (Pl. V., figs. 13, 14). The dilatations contain a small amount of residual air and act as buoys. This prolongation from the tail, containing the ends of the breathing-tubes, seems to be the most reliable distinguishing characteristic of the larvæ of the many species belonging to this genus.

Looked at from above, the larvæ of at least one species of Culex appears to float, like Anopheles, flat upon the surface; but, if put in a test tube and examined from below the level of the water, the long breathing-tube near the tail will at once be seen (Pl. V., figs. 9, 10).

The head of the larva of Culex is massive, and as broad as, or broader than, the thoracic part of the body. It is bent slightly beneath the body just as the head is in the adult insect (Pl. V., figs. 11, 12).

The larva is very active when in the water. If disturbed, it wriggles at once to the bottom, often remaining there for a considerable length of time if the disturbance is continued. When feeding, it seems continually on the move, wriggling from one place to another with a series of figure-of-eight wriggles, very different from the motion of the larva of Anopheles. It will sometimes descend to a depth of several feet.

The larvæ of the different species of Culex vary greatly in colour and habits. Some are very dark; some are light; and some are of a beautiful transparent green.

The Habitat of the Larvæ of Culex.—The larvæ of Culex will be found thriving, in warm countries, in almost every pot, tub, cistern, broken bottle, pond, or ditch—in fact, in any place where a little water lodges.

They are not particular about their diet, feeding voraciously on anything eatable, but seem to prefer animal matter and sewage. They soon attack the body of a drowned mosquito, even before it is quite dead, and I have, on several occasions, watched the older and stronger ones devour the younger or more sickly.

I recently discovered, in a building in Bombay, a number of fire-buckets, each containing, apparently, sweet water; and in each of these were living scores of Culex larvæ, in many stages of growth. What did they live upon? Mr. Hankin, Bacteriologist to the Government of the North-West Provinces of India, suggested that they lived on bacteria and tend to purify the water; but, in view of the facts above stated, it seems not unlikely that they lived mainly on each other.

The Habitat of the Larvæ of Anopheles.—Anopheles is a puddle- or even a stream-breeding mosquito. It selects small slow runnels containing algæ or green flocculent water-weed, or small puddles, or even stagnant collections of water containing green algæ. Never, as far as my experience goes, does it select sewage or foul water to breed in, as Culex does. In sewage and foul water, algæ do not grow.

The larva of Anopheles is also, to some extent, cannibalistic. If the water in a tumbler in which some have been kept without food for some days be stirred up, the little black heads of the departed ones will appear at the surface as circumstantial evidence of the cannibalistic propensities of those remaining.

Small pools or puddles on level ground, which never dry up because fed from some small spring oozing out of higher ground, are said to be best suited for the growth of algæ and, therefore, also for the breeding of Anopheles.

Places likely to be dried up or scoured out by rain will not suit them; nor do places in which the water runs fast or contains fish.

The habitat varies greatly, however, according to the climate and temperature. Grassi has asserted* that one of the most constant conditions which determines the presence of the larvæ of Anopheles is the existence on the water of Lemna (Duck-weed). This does not agree with my experience in India. Very rarely have I found these larvæ in tanks in which the water is covered with Lemna, but my investigations on this point are not yet complete. Whether it is, as I suspect, that Lemna is, to a certain extent, antagonistic to the growth of algæ, or whether it is that the larvæ have not sufficient surface space, owing to the incredibly-rapid growth of the Lemna, which covers large surfaces several times in the year, I have not yet determined.

Dr. S. P. James, of the Indian Medical Service, writing from Quilon, Travancore, says that, on looking in the large collections of water which covered the rice-fields round his bungalow, he was surprised to find Anopheles larvæ in great numbers. In this part of Travancore, they are common in the water of rice-fields, and also in the pools of water which lie between the rows of earth on fields where the native vegetables are planted in rows. Many of these rice-fields contain minnows.†

There are many instances on record where the formation of rice-fields has caused the re-appearance of malaria in places where it had become extinct.

The Nymphæ of Anopheles and Culex.—There is one stage in the life-history of both Anopheles and Culex during which they are almost identical in appearance. This is the nympha or pupa stage (Pl. II., fig. 10; Pl. IV., fig. 8).

Having reached its full size in from eight to twenty days or more after leaving the egg, the larva will be seen, if watched

* See *British Medical Journal*, February 10th 1900, p. 323.
† *British Medical Journal*, December 9th 1899, p. 1648.

carefully, to become somewhat irritable, swimming fitfully about the tumbler in which it is kept. Then, quite suddenly, a slit appears in the back; and, after some kicks and wriggles, the nymph emerges, leaving the shed epidermic cast (which retains the form of the larva) to sink to the bottom of the water.

The pupa is comma-shaped and seems to have nothing in common with its former self. It is even more active than the larva, jerking itself down to the bottom of the vessel by means of its lobster-like tail, much in the same way as a shrimp moves, and then floating up to the surface again to breathe. Instead of breathing through its tail, like the larva, it now does so by means of two shining earlike projections from the sides of the thorax, which contain the ends of the tracheæ. An examination with a lens will reveal the cases for the antennæ, wings, legs, etc., of the adult insect.

The nymph remains in this state for one, two, or three days, or even more if the temperature is low, becoming darker and darker in colour. Then, whilst at the surface of the water, the thoracic part of the pupa-case splits longitudinally; the new-born imago emerges and may be seen standing over the pupa-case which floats on the surface.

After an hour or so, under favourable conditions, the insect's legs harden; its wings unfold; and, if not imprisoned, it flies away "to join its companions in their mazy dance"—or, if a female, to work its sweet will upon the nearest warm-blooded animal.

Table of Comparison.—The facts set forth in the foregoing sections of this chapter will be made clearer by the following Tabular Statement, which (though it will not hold good in all cases) will be found useful, for purposes of comparison and identification, by those who have not made a careful study of the subject:—

Culex.	Anopheles.
Mosquito.	
1. Incapable of conveying malaria to man (?)	1. Conveys malaria to man.
2. Palpi in male about same length as proboscis. Sometimes longer and feathered (Pl. I., figs. 1. 2).	2. Palpi in male same length as proboscis and sometimes clubbed (Pl. III., fig. 1).
3. Palpi in female much shorter than proboscis.	3. Palpi in female same length as proboscis. Not clubbed.
4. Rests on wall with body parallel to, or pointing in towards, it posteriorly.	4. Rests on the wall with body at an angle of 45 deg. or more from the wall (Pl. IV., fig. 1).
5. Head below thorax, and looks hunch-backed.	5. Head, proboscis, and body in same straight line, and looks like a thorn sticking in the wall.
6. Proboscis curved and carried at an angle with the body.	6. Proboscis nearly straight, and held in same direction as axis of body.
7. Sometimes rests with body flat against the wall.	7. Body always well away from the wall.
8. Grey, brown, or greenish black.	8. Very light or dark brown.
9. Wings in most species not marked.	9. Wings in most species with 4 or 3 dark spots on the external (anterior) bargins.
10. Sings (either one or both sexes).	10. Is mute (?)
11. Bite painful.	11. Bite painless (?)
Ova.	
1. Float free in black boat-shaped masses.	1. Float singly or in little patterns.
Larva.	
1. Floats head downwards.	1. Floats horizontally at surface.
2. Breathing tubes open at extremity of a prolongation from the tail. (Pl. V., fig. 14).	2. Breathing tubes open near the tail. No prolongation. (Pl. V., fig. 13).
3. Wriggles to bottom of water when disturbed with figure-of-eight wriggle.	3. Jerks backwards along surface of water, but may go instantly to bottom when disturbed.
4. Head carried slightly beneath the thorax, as in mosquito.	4. Head carried in same plane as the body, as in mosquito.
5. Head same colour as body.	5. Head black.

Nympha.

1. Generally larger than that of Anopheles.	1. Generally smaller than that of Culex.

Habitat of Larvæ.

1. Any pot, tub, cistern, drain, ditch, or swamp.	1. Puddles or ponds containing green algæ, etc.

Sex.—The sex of all mosquitos may at once be distinguished by their antennæ. In the male, these are conspicuously feathery or plumose, forming tufts in front of the head (Pl. I., figs. 1, 2). In the female, they are plain, with the exception of some fine hairs at the base of each joint (Pl. I., fig. 3).

It is said that only the female Culex sings. This is a point upon which further study is needed. It is possible that all species are not alike in this respect. I have satisfied myself that both the male and female of at least one species of Culex sing.

It is asserted that both sexes of Anopheles are silent, and that the bite of the females is less painful than that of the female Culex, people frequently not being aware of their presence, or of having been bitten by them.

Food and Feeding.—On the second day after feeding, the ovaries appear as two thick yellow masses, loosely attached to the alimentary apparatus and to the terminal segments of the body (Pl. II., fig. 5). On the third day, the eggs are usually laid and the insect frequently dies if it has not been fed again on the previous night.

The male and female of all mosquitos each possesses a proboscis, but only the females bite and suck blood. In some species (*Corethra*, for example) the proboscis is so short that it is almost invisible to the naked eye.

According to Grassi,* Anopheles bites only at sunset and sunrise. Elsewhere, it is said† that they bite at night, and sleep

* See *British Medical Journal*, Sept. 9 1899, p. 684.
† *Ibid.*, Sept. 30 1899, p. 869.

during the day-time on walls, where they can be caught easily by placing a test-tube or a bottle slowly over them. The tube is then stoppered with cotton-wool.

In forty-eight hours after feeding, the stomach becomes empty. Then the eggs are laid and the insect is ready to feed again. Captive insects may be fed by placing the mouth of the tube on the skin. Presently Anopheles will "lay hold" and gorge itself, even in the day-time. It even voids blood while sucking. Grassi corroborates this, and says* that Culex is, in this respect, extremely refractory. He also says† that blood is digested in Anopheles about twenty hours sooner than in Culex. This, if a fact, is extraordinary, and may be correlated in some obscure way with the development of the malaria parasite.

Dr. Bancroft says‡ that, if mosquito larvæ (he is speaking, probably, of Culex) are fed partly on animal matter they grow faster and to a larger size.

I have several times seen the larvæ of Anopheles die within the hour when transferred from the tumbler in which they had lived to the tumbler in which Culex had been, and was being, hatched out, in water from a drain.

My own method of observation has been to keep the larvæ in a series of tumblers, with fine mosquito netting over them, changing the water from time to time, or adding more from the tank or puddle whence they came, which should, if possible, contain whatever they have been feeding upon. When they reach the nymph stage, I have transferred them, with a few drops of water, to one of a series of inch or inch-and-a-quarter glass test-tubes, kept in a stand. Each tube is labelled and plugged at the top with cotton-wool. Inside, is placed a strip of rough white paper about the width of the tube for the mature insect to show itself upon when it emerges from the pupa case, which it does in one, two, or, perhaps, three days. These pupa-

* See *British Medical Journal*, Feb. 10 1900, p. 324.

† *Ibid.*, p. 323.

‡ *Journal of Tropical Medicine*, Jan. 1900, p. 151.

cases remain floating at the surface, and often serve as tell-tale evidence of the existence of a breeding haunt.

The nymphæ do not, of course, require food; but, to feed the mosquitos, a section of ripe banana is placed each day, or every other day, in the mouth of the test-tube, instead of the cotton-wool. Both males and females suck the juice of the fruit.

It is not safe to observe mosquitos under ordinary mosquito netting, arranged above the tumblers in which they have developed; for the females (particularly those of Anopheles) can pass through the meshes with the greatest ease, wherever there is an angle, a crease, or a corner in the netting for them to push their legs against. The males can, also, pass through, but the females are the most determined. I have watched fifty or more pass through into an outer netting in the course of a morning. Where the net is stretched tight, I have not seen them get through. The material known as "white leno" is said to be more serviceable.

Will mosquitos suck blood from a corpse?

This is a question of some interest, and affords food for reflection upon the coagulation of blood and upon the duration of life of blood-parasites after the death of their host. On one occasion, in Nigeria, I proceeded to a hut in order to make a *post-mortem* examination upon the body of a white non-commissioned officer who had died from Black-water Fever three and a half hours previously. On lifting the corner of a mackintosh sheet which had been laid over the body, I was surprised to see a cloud of mosquitos rise from beneath it. The sheet was replaced, leaving the shoulder and neck slightly uncovered as before; and, in a few minutes, a number of large brown Anopheles were probing the corpse in their characteristic attitude.

Fecundation.—Mosquitos are fecundated on the wing shortly after feeding. They are believed to return to the spot in which they were born to lay their eggs. Hence the places probably remain permanent breeding-haunts.

According to Professor Celli, Anopheles is capable of producing, during the warm season, five generations in one season, forty days being the time occupied from *ovum* to *imago*.*

Length of Life.—Ross, Bancroft, and others have proved that mosquitos may live in captivity as long as eight weeks, and there is little doubt that, if conditions require it, they can, in the tropics and sub-tropics, remain alive for long periods in dark corners of houses.

But what becomes of them in cold climates?

When I have been in Norway it has always been a puzzle to me to explain how the millions of mosquitos, which are such a pest in most Norwegian valleys, and even worse at the Saëters high up in the hills, come there. I have found it impossible to fish in some of the valleys without a head-net and gloves. Did the mosquitos themselves, or did the eggs, or the larvæ, or the pupæ, like the Lemmings, survive the long winter months beneath many feet of snow?

How much desiccation can the eggs and the larvæ of Anopheles withstand?

It is said† that if the puddle dries up without complete desiccation of the mud at the bottom, the larvæ survive and spring into activity again when another shower falls. When, however, the rain holds off for four days, not a single larva, large or small, can be detected when rain fills up the puddle once more. In twenty-four hours, however, a fresh crop of newly-hatched larvæ may be found.

Whether or no the eggs have withstood the desiccation, or a fresh lot of eggs has been laid, has not been ascertained. Either of the following hypotheses would explain the continuance of the species in a locality:—(*a*) The eggs can withstand prolonged desiccation, or (*b*) the adults can hibernate throughout the dry season.

* See *British Medical Journal*, Feb. 10 1900, p. 324

† *Ibid.*, Oct. 14 1899, p. 1033.

CHAPTER VII.

METHODS OF DESTRUCTION OF MOSQUITOS.

Let us summarise what we have learnt so far.

First, certain mosquitos convey malaria from man to man; secondly, those mosquitos belong only (as far as we know at present) to the genus Anopheles; thirdly, the larvæ of all species of Anopheles have certain peculiarities by which they can, with a little skill, be recognised at sight.

This being so, it is clear that the next thing we must inquire into is whether it is not possible to declare war against Anopheles, and endeavour to exterminate him (or, at least, to greatly lessen his numbers), by attacking him in his larval stage, when he is most vulnerable.

A recent estimate gives the number of people who die in India each year, directly and indirectly, from malarial fever alone as high as 5,000,000; and, inasmuch as vast sums have been spent by nations and private individuals for preserving the vine from oidium and phylloxera, it is surely worth while that still larger sums should be expended in the effort to discover some means of removing the cause of such frightful human mortality as that which arises from malarial fever.

It is well for Culex and other genera that we have as yet no indictment against them. It is fortunate also for us; for it would be almost an impossible task to deal, once a week, with every tub, pot, ditch, puddle, or well, which contained the larvæ of Culex.

With the knowledge that the larva of the noxious Anopheles can be easily recognised; that it breeds in waters containing algæ; and that its breeding places are proved (as will be shown later) to be always close to the haunts of man or to human habitations—it would seem that our task is, at least, within the bounds of possibility.

Having discovered the breeding-places, the first method which suggests itself is to fill them up, if they are of small extent, with a few cart-loads of earth. If, however, their area is large, then drainage would seem to be the only successful plan. Many cases in which drainage and cultivation have reduced malaria to a minimum can be cited—for example, Lincolnshire in our country. On the other hand, there are localities where malaria remains in spite of both cultivation and drainage.

But drainage is, of course, expensive, and few towns in the tropics could afford to drain a large malarious area; moreover, dry cultivation, although naturally the best against mosquitos, and consequently against malaria, is unfortunately often not remunerative.

We must, therefore, consider drainage as a crude measure and not feasible in the majority of cases. Flushing, another crude measure, might be more successful in a few cases.

It is necessary, therefore, to discover other means.

Larvicidal Substances.—If a breeding-haunt cannot be either filled in or drained, we next turn our attention to some substance that will kill the larvæ in the water.

The larvæ have to come up to the surface of the water to breathe. This being so, it does not require a great stretch of imagination to see that, if we can find a substance which will float evenly over the whole surface of the water, the imprisoned larvæ, being unable to breathe, will soon die. Such a substance is petroleum or kerosene. A very small quantity of this will cover a considerable area, provided the surface is not influenced by wind or running water. Not less than one ounce for each ten square feet of surface should be used.

Any other oily substance will act equally well, provided it is light and diffusible; but the disadvantage of all such substances is that they foul the water for drinking purposes, unless it is drawn off by means of a tap below the level of the surface.

Tar has been recommended as being efficacious, and in my opinion is the best of all the cheap larvicidal substances. If petroleum is used, it evaporates so soon that the place must be treated afresh every three days or so. But, if a small quantity of tar or an old tar-barrel is placed in the pond or puddle, the water remains for weeks coated with the oily products of the tar, which kill the larvæ and prevent the mature insects from laying their eggs in the water.

Professor Celli and Dr. Casagrandi have spent much time in the investigation of this matter. Their work is thus described *:—

Among the mineral substances which kill the larvæ, potassium permanganate, even 5 per cent., acts slowly in clear water, and in marshy water it is practically inert, having to oxidise all the organic substances. For the same reason, its action is destroyed in sulphurous waters. Lime, copper, iron sulphates, and ammonia, even in very large proportions, act rather slowly. Sulphurous water is one of the most active substances; corrosive sublimate, as strong as 1 per cent., kills the larvæ slowly and does not kill the nymphæ.

Among the vegetable substances potent poisons to the larvæ are the leaves of strong tobacco, and some of the insecticide powders of commerce, which are obtained from the unexpanded flowers of chrysanthemums. The commercial extract of tobacco, a saturated aqueous infusion of quassia, of solanum nigrum, or of daphne quidium, are also efficacious. Some of the aniline dyes are likewise efficacious.

Of all the substances, water saturated with sulphurous oxide, or potassium permanganate mixed with hydrochloric acid act the most rapidly.

Salt water, which at 5 to 10 per cent. kills the larvæ in

* See *British Medical Journal*, September 9th 1899, p. 683.

fifteen hours, in concentrated solutions, kills them in thirty minutes, and the nymphæ in an hour.

Caustic lime, ammonia, and chloride and carbonate of lime only act in very high proportions. Of the more powerful bactericidal substances, formalin and lysol are not very efficacious, and corrosive sublimate is even less so.

Young larvæ are much more easily destroyed than the old. With a rise of temperature, the time for the destruction of the larvæ and nymphæ by different substances is shortened. The first to lose its larvicidal action is petroleum, which soon evaporates and no longer covers the surface of the water. It does not kill the fish or lower forms of life. The insecticide powders are poisonous to some worms, molluscs, and fishes. The staining substances, if concentrated substances are used, destroy all animals in the water, and their action is of considerable duration.

Culicicidal Substances.—According to the same observers,* the substances which kill the mosquito itself may be divided into odours, fumes, and gases.

"Among the odours which caused death were turpentine, iodoform, menthol, nutmeg, camphor, and garlic. Among fumes were tobacco, chrysanthemum flowers, fresh eucalyptus leaves, quassi wood, pyrethrum, and also simple wood smoke. Among the gases the most practical and efficacious was sulphurous oxide."

Mosquitos also detest the smell of many of the essential oils, especially, it is said, the oil of lavender. Soaps made with the extracts of tobacco or turpentine are useful. The latter is said to prevent mosquitos from biting a person in the open air for one or two hours.

Three teaspoonsful of powdered cineraria, mixed with a little nitre and ignited, is sufficient to kill all the mosquitos in an ordinary-sized room. A sulphur candle is also of service.

* See *British Medical Journal*, September 9, 1899, p. 683.

A cyanide jar is useful for killing specimens for examination.

A better knowledge of the habits of mosquitos (that is, of the place and time of their breeding) may possibly render their destruction easier.

M. Grellet has recently communicated to the French Academy of Medicine* some interesting observations on the influence exercised by lime on a malarious soil. He says that, up to the year 1840, malaria was rife among the inhabitants of Châtillon-sur-Loing; but, after that date, it disappeared completely. Between 1824 and 1840, lime was applied to the soil for purely agricultural purposes; and, by the time the whole plateau had been thus treated, malaria had disappeared. No difference had been made in the agricultural methods employed; nor had any drainage or sanitary works been carried out. He mentions other instances of the sort. The value of a process which at once checks malaria and improves the soil is obvious.

* *Revue Scientifique*. October 21st 1899, p. 530. (See also *British Medical Journal*, December 9th 1899, p. 1625.)

CHAPTER VIII.

THE ÆTIOLOGY OF MALARIA.

The Seasons.—Even with the small amount of knowledge we already possess of the life-history of Anopheles and of the many factors (such as temperature, rainfall, food, etc.) which influence its reproduction, we begin to realise how it is that malaria has such a close connection with the seasons—so close that malarial fevers are named after the seasons.

Professor Celli says that,*

"in order to follow exactly the annual course [in Italy] of malaria, it is necessary to distinguish carefully the primary forms from the recurrents, and the three principal forms of malarial fevers—the spring and quartan, tertian, and summer tertian.

"It is then seen that the true malarial season—that is, the season of primary infections—is the second six months of the year. Its sequels, with the recurrent fevers, are prolonged through all the first six months of the following year, gradually declining from January to June. The fevers, therefore, of the first half of the year are generally recurrents of the infections contracted in the second half of the preceding year.

"By means of these recurrents, the seed of contagion is maintained. In the summer season, it is transmitted by the agency of mosquitos and opens the subsequent epidemic year.

"The epidemic year of malaria, therefore, extends from the July of one year to the June of the following year. It is remarkable that the quartan is the last to appear and also the last to recur. The mild tertian and the severe have a similar, but not identical, annual course, the second in summer and autumn notably prevailing over the first—hence the name æstivo-autumnal tertian.

"This tertian is the first to cease recurring, and consequently in the spring mild tertian and quartan prevail and have, therefore, *a fortiori* been called spring fevers.

"The life of Anopheles is [in Italy] in direct and intimate relation with the annual epidemic course of malarial fevers.

* *British Medical Journal*, February 10th 1900, p. 303

The new generations begin to bite in the second half of June and in the first half of July. Towards the end of June, the first infected mosquitos are observed, and their number increases in July and August."

The following table compiled by Professor Celli illustrates his meaning more clearly.* The *italics* are mine:—

	Æstivo-autumnal, (*Severe Summer Tertian.*)	Benign Tertian.	Quartan (*Spring*).
March 15th to June 30th...	3	6	12
July	10	3	0
August	26	7	1
September...	18	3	1
October	10	2	3
November...	2	1	2
December	0	0	0

It will be seen that, from July 1st onwards to the summer and autumn, the prevalent type of disease changed completely from what it had been from March to June.

At Grosseto, in Tuscany, the dangerous malarial season of first attacks is said to last three months only, beginning in the last week of June. Three weeks after the temperature has risen to 27 deg. C, the sudden outbreak of malaria commences. Celli says†:—

" Certainly the temperature influences the sudden appearance of the fevers in July, and their prolongation in the autumn and sometimes to the beginning of winter if the cold weather sets in late."

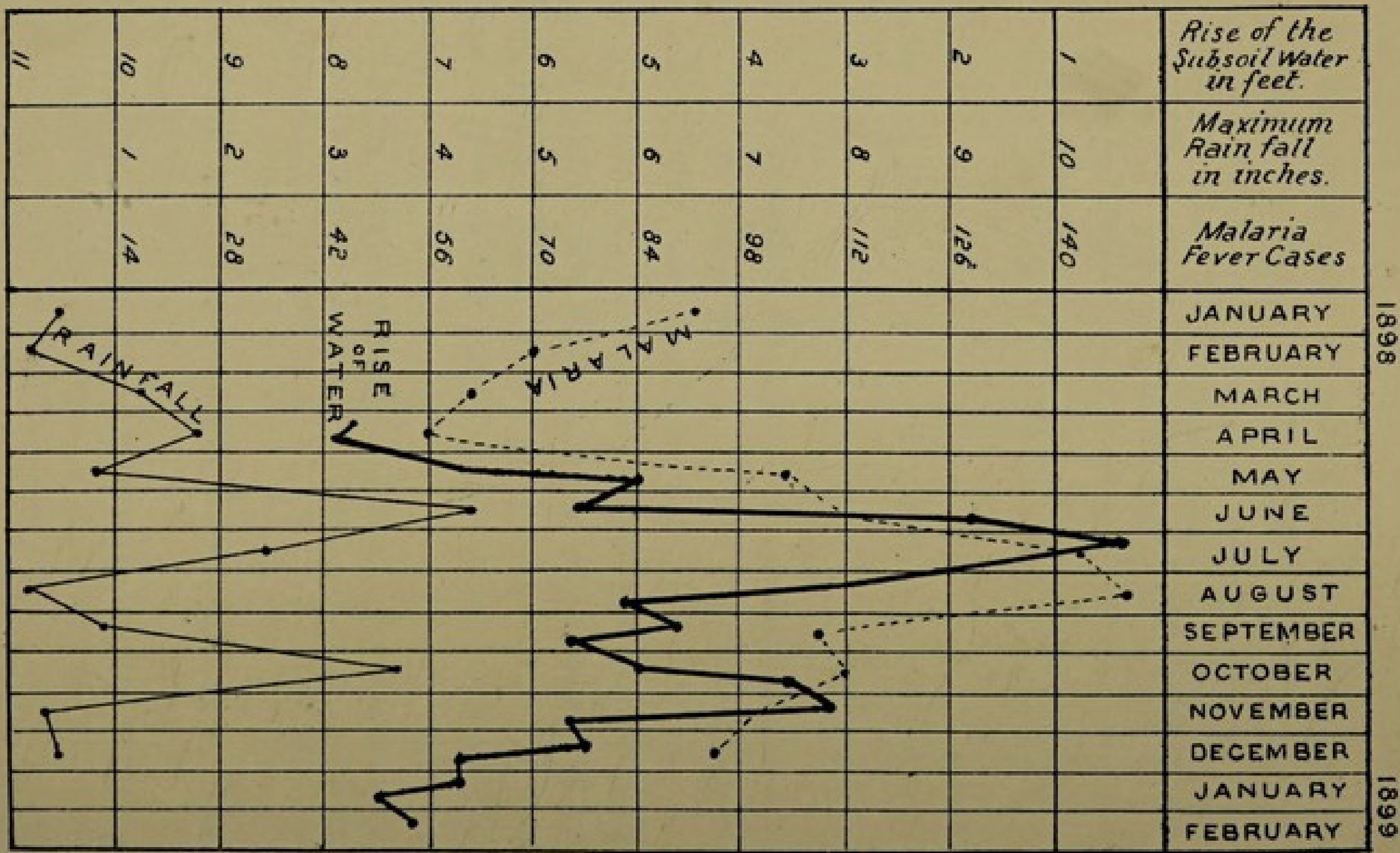
Dr. Strachan, Chief Medical Officer at Lagos, West Africa, writes‡:—

"I have, for many years, noted that the greatest number of the cases of malaria occur shortly after the cessation of the rains, and but few during the rains, unless the latter had been interrupted by short periods of dry hot days. It seemed, therefore, to me that saturation of the soil with water (or, in other words, rise of the

* See *British Medical Journal*, February 10th 1900, p. 324.

† *Ibid.*, Feb. 10th 1900, p. 303.

‡ *Journal of Tropical Medicine*, Feb. 1900, p. 181.


1898
1899
Rise of the Subsoil Water in feet.
Maximum Rain fall in inches.
Malaria Fever Cases
1
2
3
4
5
6
7
8
9
10
11
10
9
8
7
6
5
4
3
2
1
140
126
112
98
84
70
56
42
28
14
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MALARIA
RISE OF WATER
RAINFALL

sub-soil water) might eventually be found to have a causal relationship to malarial fever.

"It is interesting to note on the accompanying chart, which is the outcome of a series of observations in respect to the curves of rainfall, rise of ground-water, and malaria at Lagos, during 1899, that the relationship of the malarial curve to that of the rainfall, confirms the opinion expressed above, an opinion formed originally in Jamaica. It will be seen that the height of the malarial curve follows very closely that of the ground water, and at a distance of several days the crest of the rain curve. Owing to the absence of sufficient elevation above the sea-level, the ground water here rises to the surface and remains there for some time. Keeping in mind the mosquito theory, therefore, it is not difficult to find an explanation in a place like Lagos, where a virulent form of malaria is common and where Anopheles is found in myriads."

Some medical men of large experience in the tropics have maintained that the greatest number of cases occur during the rains. This may be so, but it is certainly not my experience in West Africa with regard to first infections.

A series of observations similar to those of Dr. Strachan, but extending over at least one year, from several places in which malaria is prevalent, would be of very great interest, particularly if in conjunction with observations on the hatching-out of Anopheles.

It will be found that the height of the fever curve (that is, the time of year at which the greatest number of primary infections occur) is different in different countries and, in fact, in different places in the same country. It will be found, also, that these differences have a very close connection with the temperature, rainfall, etc. We know that the temperature, rainfall, etc., directly influence the hatching-out of Anopheles, but it remains for us to prove that, in all places, the hatching-out of Anopheles coincides with the fever curve.

Soil.—It has often been reported that the *disturbance of soil* has given rise to an outbreak of malarial fever; and it is a fact that the disturbance of soil, if on a large scale, may give rise, indirectly, to such an epidemic, particularly during the warm season. Dr. Manson says*: —

"The medical history of Hong Kong may be cited as an illustration. At the commencement of the occupation of this island by the British, for a short time, it was healthy enough. Then, on its cession being completed, and when barracks and houses were being built and roads laid out, it became excessively unhealthy, the soldiers dying by the hundreds of pernicious fevers. In time the sickness and mortality gradually decreased; and now, so far as malaria is concerned, the city of Victoria is healthy. But, even at the present day, wherever in the outskirts, in the course of construction of houses, roads, forts, and similar works, soil is turned up, fever, often of a most pernicious type, is nearly sure to break out among those engaged in the works."

Scores of similar instances might be mentioned, and many theories have been advanced to explain them. But now a vivid picture of what happens, probably, in these cases rises up before us.

We have, to begin with, one essential of an epidemic—a large collection of men, say European soldiers, or coolies making a railway. They are housed in barracks or open sheds, and no mosquito nets are provided. Mosquitos, including Anopheles, are plentiful, the more so owing to the unusual supply of food. Possibly, a pond or puddle close by, not previously used as a breeding place, or excavated to obtain earth for an embankment, is, from the same cause, swarming with larvæ.

If malaria is prevalent in the neighbourhood, the thing is simple; but, if not, one of the men has a recurrent attack, or a new-comer has been bitten by an infected Anopheles on his journey, and at (let us say) 4 p.m. on April 30th he commences to pass through the stages of a typical attack. He is bitten repeatedly that afternoon and evening by both Culex and Anopheles; but Culex, we know, is not susceptible, and the Anopheles do not become infected, because the malaria parasites in the corpuscles of that man's blood are not yet mature and therefore cannot flagellate.

* *Tropical Diseases*, p. 98.

At midnight, a few mature forms might be found. From then onwards through the morning (May 1st), any Anopheles which draws his blood becomes infected.

What then happens?

On May 2nd or 3rd, the external wall of the stomach of that mosquito is found, if examined, to be studded with the earliest form of pigment cells (coccidia).

These go on developing until, on May 8th or 9th (or later, according to the temperature), the adult coccidia (zygotes) burst and pour into the cœlom of the insect their minute reproductive elements—the thread-like bodies (zygotoblasts). A few hours afterwards, they are to be found in most of the tissues, including the veneno-salivary gland.

The man has probably had a second rise of temperature, which, we will suppose, was at the same time of day as before, on May 2nd. If the same Anopheles (which has probably been feeding every other night) happens to have bitten the man again on the morning of the 3rd, when his second crop of parasites is mature, then we shall find, on examination, another crop of coccidia in its stomach wall. These will mature in their turn, and will reach the salivary gland about May 11th or later.

In any case, on the night of May 9th, and on every night, or on alternate nights, according as it fed, for some time afterwards, that Anopheles will infect any person whom it bites. If that person be restless, it may, before sucking its fill, inject half a dozen doses of sporidia with the secretion of its salivary gland.

On May 15th, 16th, or 17th (leaving five days as the minimum time for incubation), any of those men bitten would develop an attack of malaria; and each of those men, when their parasites were mature, would, if bitten by Anopheles, initiate attacks in other men, and so on.

It is thus easy to understand how an epidemic of malarial fever is fostered. When we come to think that half a dozen Anopheles may have bitten the original man on May 1st, and the same ones and half-dozen more, on May 3rd, after his second rise of temperature, and that, owing to bad treatment or want of quinine, he may have had several rises, being bitten each time, we can easily understand the widespread nature of that epidemic.

Bignami and Bastianelli say*:—

"Wherever people congregated, there also the Anopheles gathered. For instance, the harvesters slept in the open until June 22nd; but, on that date, a large company of them were housed in a big granary which served them as a dormitory. On the 23rd, after a long search, a single Anopheles was found in the granary; on the morning of the 24th, eight were captured; and on July 1st, no less than 366."

They also† mention another instance where 42 corn-threshers commenced work near Ostia, in the Campagna, on June 21st and continued till the beginning of August. Some of these men had had fever the previous year and were suffering from relapses when the work was begun.

"Of the Anopheles collected in the huts of 7 of these people on July 1st, 2 out of 7 were found to be infected [with the coccidia of malaria]; of those collected on the 9th and 10th, 2 out of 17; of those captured on the 17th, 15 out of 32, or about 40 per cent.; and on July 20th the number of infected Anopheles had risen to 11 in 17, or about 64 per cent., some of them presenting ruptured capsules and mature sporozoites. . . . At the end of July and the beginning of August, nearly all the men who had slept in those huts were affected with æstivo-autumnal or tertian fever.

"Evidently they had been infected by the mosquitos which had invaded their huts and which had, in their turn, taken the parasites from those amongst the labourers who were suffering from relapses of fever. The progressively increasing number of Anopheles found infected, explains in the clearest manner, it appears to us, the final outbreak of the disease amongst nearly all the labourers."

It can now no longer be admitted that the simple stirring up of the soil in malarious places determines the liberation of germs of this infection; nor is it likely that breathing the dust of

* *Lancet*, Jan. 13th 1900, p, 82.
† *Ibid.*

dried up marshes can have any effect in the production of malaria.

Water.—Hitherto it has been usual to attribute many attacks of malarial fever to the drinking of bad water. Now, however, we know that the water of swamps and jungle-pools has much less danger in store for us than we imagined.

Everyone who has travelled in Africa, can call to mind occasions on which he has been obliged to drink foul, and sometimes stagnant, swamp water, and his subsequent jubilation, five days or so later, on finding he has escaped the expected attack of fever.

One Italian experimentalist has recorded the fact that, for a long period, he drank quantities of water sent to him from various malarial localities (some samples containing larvæ, others the bodies of mosquitos), but that he escaped with nothing worse than a mild attack of dysentery.

It cannot, as yet, be said that the possibility of infection by drinking water, by inhalation, or by food, has been absolutely disproved; but there seems, nevertheless, to be no evidence whatever to show that malarial fever may be acquired through any of these channels.

Geographical.—Dr. Manson says*:—

"The geographical range of malaria is very great. It extends in the Northern hemisphere from the Arctic Circle to the Equator, and in the Southern probably as widely. It is not uniformly distributed throughout this vast area, but occurs in limited endemic foci, which tend, speaking generally, to be more numerous and larger as the Equator is approached."

It becomes, therefore, important for every observer to help in mapping out the geographical distribution of Anopheles, in order to see whether it agrees, in all cases, with the known range of malaria.

A study of the mosquitos of South America, for example, would

* *Tropical Diseases*, p. 95.

be particularly interesting; for, south of the Brazils, malaria is, I believe, unknown or very rare. Nevertheless, this part of South America is supplied with mosquitos perhaps more generously than any other place in the world. On the Rivers Plate and Parana, mosquitos can be seen in clouds in the day-time, as locusts are often seen.

My diary tells a painful tale of woe occasioned by a walk I took, some years ago, along the banks of the Parana, above the City of Rosario, or ornithological purposes. For the greater part of the day, I passed through miles of a tall umbelliferous plant which grew in profusion everywhere. From this plant, as I advanced, rose clouds of small brown mosquitos, which settled all over me, making a gory mess of hands and face. Their bite seemed to cause very little pain or inconvenience at the time. Twelve hours afterwards, however, I was in bed with a temperature of 102 deg. F., vowing vengeance on all mosquitos, with my eyes closed by œdematous eyelids, and with my lips, fingers, and ears double their normal size. A splitting headache and attacks of vomiting completed my discomfort. But no malaria followed. Before leaving the country, I saw other cases of similar acute poisoning from mosquito bites, but without the accompaniment of malarial fever.

Many of the South Pacific Islands are said to be entirely free from malaria.

Malaria is not contracted in the desert. "In the Sahara [says Manson*] there is no malaria, unless in the oases. In many of these, it is rife—in Biskra, for example."

From the scientific, as well as from the medical, point of view, a study of the mosquitos of the West Indies would be of interest. In the island of San Domingo, they are remarkable for their conspicuous and even brilliant markings. A very fatal form of malaria, called bilious remittent fever (the *fevre billosa* of Spanish

* *Tropical Diseases*, p. 97.

writers), is prevalent in several of the islands at certain times of the year. The native doctors continually mistake it for yellow fever.

I retain a vivid recollection of certain mosquitos in San Domingo. On the few drier and wooded parts of a big morass of many miles in extent, at the mouth of the river Yuna, in that island, is to be found growing a good-sized tree, belonging, possibly, to the Magnolias. The natives call it the "Pitch Tree," because they produce from its fruit a black substance which they use as pitch. Beneath this tree, nothing seemed to grow, the ground being covered with its large dead leaves. If I wandered carelessly into one of the open spaces thus formed beneath these trees, I was instantly attacked by the biggest, blackest, and most vicious mosquitos it has ever been my lot to encounter. I had to make an immediate retreat—in fact, to rush through the thickest undergrowth that could be found, or the attacking party would follow me like a little swarm of hornets.

There are said to be several non-malarious areas in India—Jasalmir State, for example. It will be interesting to know whether Anopheles is to be found in that State.

Altitude.—Mountainous districts are usually free from malaria, because, if there is any slope, the water-courses and puddles are scoured out by the rain, often to the bare rocks, and what water remains soon drains away. In such places, algæ (the chief food of the malaria-bearing mosquito) cannot grow, and in them, therefore, Anopheles cannot reproduce its species.

Altitude has, in itself, no influence whatever upon the production of malaria, except in lowering the temperature below that required for the hatching of mosquitos and for the development of the coccidia. The temperature in a narrow, ill-ventilated, imperfectly-drained valley, at an elevation of several thousand feet, may, however, be so high that it becomes just as malarial as places in the plains below.

Swamps and Morasses.—Why is malaria always contracted near water?

Because mosquitos require water for the reproduction of their species.

Why is it associated with swamps and morasses?

Because these are almost a necessity for pools containing algæ.

This brings us to some interesting points upon which further knowledge is needed.

The Sierra Leone Expedition, last year, is said* to have reported that

"in not a single instance have the breeding pools [of Anopheles] been found far from human habitations. The females must pass frequently between the pools where they lay their eggs and the houses where they obtain their food. It must, therefore, be convenient for the one to be as near the other as possible. If we find adult Anopheles in a house we may generally assume that the breeding-puddles are close by."

Morasses and swamps usually swarm with mosquitos, but in most, if not all, cases they will be found to be Culex, the females of which suck the blood of cattle which are herded on the few dry spots, wild animals, birds, and man if he is present.

Where do these mosquitos breed?

It is commonly believed that, owing to the danger incurred from small fish, they cannot live in the water of big morasses, but it is a fact that they can; for, at certain times of the year, when the river with which these big morasses are generally connected is low, the water percolates so slowly through many miles of the densely-packed rushes that grow in these situations that, in parts, it becomes actually stagnant, and there mosquitos breed in abundance. Through these reeds, fish probably cannot penetrate.

I have several times identified the larvæ of Culex in such situations on the upper waters of the River Niger, whilst being

* See *British Medical Journal*, Oct. 14th 1899, p. 1033.

forced through the rushes in a canoe, many miles from any human habitation. But I have never identified the larvæ of Anopheles in similar situations. The latter are, however, less conspicuous than those of Culex and may have been overlooked.

Anopheles is, it will probably be found, a domestic mosquito, breeding only near human habitations.

If the vicinity of a morass is uninhabited, then, in all probability, Anopheles will not be found in it. If, later, it becomes inhabited, Anopheles will soon appear, and its breeding spots will be found to be within a hundred or two hundred yards of the habitations.

Sarrasin, in his recent interesting work on the Celebes, states that malaria is not contracted in the jungles, but only near villages. My own experience in West Africa is similar.

A country in which malaria is prevalent, but in which Anopheles does not occur, has yet to be found. If that country is found, then the statement that Anopheles is the only genus of mosquitos which can convey the fever will be disproved. Further, a country in which Anopheles occurs but in which there is no malarial fever has yet to be found.

The oft-repeated travellers' tales about malarial fever in uninhabited countries have still to be substantiated. If a primary attack could be proved to have been contracted more than eight days after entering an absolutely uninhabited country, it would clearly point to the fact that monkeys, apes, or some other animal inhabiting that country were capable of suffering from human malaria, and we should assume that it had been conveyed from them to the human patient by Anopheles.

Inoculation.—Koch has shown* by experiment that the higher apes cannot be infected with human malaria by injections of blood drawn from human patients suffering from malarial fever; but

* *British Medical Journal*, Feb. 10th 1900, p. 326.

he has not shown that no wild animals can suffer from human malaria conveyed by the agency of mosquitos.

It is doubtful, judging from our knowledge of the double cycle of life of the sporozoa, whether man or animals can be infected with malaria by injections of malarial blood. It is possible, however, that the injection of a large quantity of blood containing active sporulating parasites might produce an attack. The results of some experiments (of which I am, unfortunately, not able to give details) seem to show that it can.

Inasmuch as our knowledge of the form which the parasite takes during its periods of latency is as yet limited, it might be argued that, if some form of the parasite can return after several months to the peripheral circulation and re-sporulate, is it not possible that the crescent bodies, or blood from the spleen or liver of a malarial patient, if injected into the blood of an animal or human being, could produce an attack? Further experiment only will show.

Winds.—No relation can be shown between winds and malaria. On the contrary, winds tend to clear the air; for mosquitos cannot fly in a wind.

Nor can any relation be shown between mists or fogs and malaria, except that they are associated with what we ambiguously call "chills"—often the immediate cause of a recurrent attack. The once-dreaded "miasmas" of marshes and mangrove swamps have now few fears for us.

As Ross has observed, a puddle of water under a bedroom window may be infinitely more dangerous than a square mile of swamp or rice-fields a mile away.

Again, Manson says*:—

"It is certain that some thousand or fifteen hundred yards of water between a ship and a malarious coast will usually suffice to secure immunity to the crew. . . . A similar distance from a malarious source is probably quite as effective. . . . One village may be sickly, whilst a neighbouring one may be healthy."

* *Tropical Diseases*, p. 99.

Ship Malaria.—Several instances are on record of outbreaks of what was reputed to be malaria on ship-board on the open sea. As it is not likely that the disease can be conveyed in drinking water, we now refuse to accept the diagnosis of malaria in such cases.

But it may be quite possible that Anopheles, having once gained access to a dark and ill-ventilated cabin, may remain there a considerable period after the ship has put to sea; and, if a case of malaria occurs in that cabin, it is conceivable that the insect, having fed upon it, might convey the infection to others.

Immunity.—For the acquirement of artificial immunity, most is at present to be hoped from methylene-blue.*

Koch, in his second report to the German Colonial Office, on the work of the Malaria Expedition to the Dutch Indies, conducted under his direction, mentions some interesting discoveries with regard to the subject of immunity.†

It is well known that malarial attacks are more severe, more common, and much more dangerous in young children than in adults; and Koch's experience in East Africa strengthened his knowledge of this fact. Therefore, in order to judge of the peculiar malarial conditions of certain regions, he examined a large number of children in places which appeared especially favourable for malaria.

In the first village, he found the adults apparently healthy, and they stated that they suffered little or not at all from fever; but, out of 86 children whose blood was examined, parasites were found in 8 (9.2 per cent.). Of the children under one year, 16 per cent. were malarial; and, of those above that age, 4 per cent.

In the second village, out of 141 children examined, 18 (12 per cent.) were malarial. Of those under one year, 15.5 per cent., and of those over one year, 7 per cent. were malarial.

* Celli, *British Medical Journal*, Feb. 10th 1900, p. 305.
† *Ibid*, Feb. 10th 1900, p. 325.

In a third village, 1,000 metres above the sea-level, 189 were examined; of these, 43 (22.8 per cent.) were found with malaria parasites. Of those under one year, 41 per cent., and above one year, 14.6 per cent. were malarial.

"The rapid diminution in the frequency of malaria with increasing age can be explained [Koch thinks*] only in this way—that men in these malarious regions, where they are constantly exposed to infection, go through it in early youth, and, if they do not succumb to it, acquire a greater or less complete immunity."

It has often been noticed in Africa and other malarious countries that those soldiers or recruits who are drawn from Europe or non-malarious districts hardly ever escape infection, and suffer more severely than those from a malarious district, and that the latter show a certain power of resistance.

Koch thinks† that these observations also

"afford a plausible explanation of the fact that children of Europeans in the tropics, where malaria exists more or less everywhere, thrive so ill; namely, that in regard to malaria they are obviously in a much more disadvantageous position than native children born of immune parents; when the latter become infected with malaria, they have it in a milder form than the highly susceptible European children. Finally, the prophylaxis of malaria, as far as it has to do with diseased men, may derive the greatest advantage from this knowledge."

* *British Medical Journal*, Feb. 10 1900, p. 326.
† *Ibid.*

CHAPTER IX.

THE PROPHYLAXIS OF MALARIA.

It remains to point out the new lines on which the prophylaxis, or prevention, of malarial fever should be carried out. Our watchwords must be:—Sanitation; Quinine; Isolation; Education. Each may be considered in turn.

Sanitation.—Space does not permit of a full description of the various means of hydraulic sanitation; but, to those who have read the foregoing pages closely, it will be evident that the sanitation for the prevention of this particular disease becomes easy in proportion to the advance of our knowledge of the biology of the hurtful species of mosquito.

In all malarious districts, it is necessary to remove stagnant water and to drain or fill up useless ponds and ditches, in order that the larvæ may not be bred in them. Water-taps which, with the exercise of carelessness on the part of the people, can be left running should be avoided. All systems with surface and open channels will be efficacious in proportion to the velocity of the water. Levelling the ground, or in towns paving it, so that the sub-soil water does not appear at the surface, is also most important.

The planting of trees is injurious, as likely to harbour mosquitos; but, in low situations, where there is danger of the subsoil water coming to the surface, palms or quick-growing trees act beneficially in subtracting a large quantity of water and helping to dry the soil.

A house, camp, or town will be healthy in a malarious district if it be on an elevation where the insects from the plains or a neighbouring marsh do not reach, and where there is sufficient wind or free current of air through all the buildings, rooms, or tents. A house in a lower situation should be raised upon supports; the area of windows and doors should be large; the walls should be of plain deal or other smooth substance; and superfluous curtains, ornaments, and dark corners should be avoided.

In my experience, a tent of the I. P. pattern has the great disadvantage that the wind cannot circulate freely through the upper parts of it, and the flaps for the "kanâts" are exceedingly well fitted for harbouring numbers of mosquitos through the day-time.

Quinine.—It is true that an ideal prophylaxis would be attained by removing the conditions which are necessary to the development of Anopheles in malarious areas. But, seeing that malaria is now proved to be a contagious (and, in fact, an infectious) disease, by the agency of certain mosquitos, "the careful treatment of the malarial patient constitutes one of the principal tasks of social hygiene."

Quinine, as is well-known, is the specific disinfectant for amœboid organisms and, consequently, for the malarial parasites in their amœboid stage. Unfortunately, however, quinine does not act upon the mature forms of the parasite (the crescents, for example), which are, strictly speaking, not amœboid.

It is, therefore, important that the quinine should be given early in order to prevent the parasites from reaching maturity. If they are allowed to do so, they become capable of remaining for weeks, not only in the deeper organs, but in the peripheral circulation.

Isolation.—Hence it is at once apparent how important isolation becomes. A patient, in this condition, is a source of infection and, therefore, of danger to others, and should at once be removed to a place where there are no malarial mosquitos, or isolated either in a properly-arranged mosquito net or a room protected by mosquito-netting.

It is needless to point out that an impervious mosquito-net is the surest and safest preventive, and the best and readiest means of isolation. Numberless instances can be mentioned of persons living in notoriously malarious places having remained comparatively free from fever, owing to the careful use of mosquito-netting under all possible circumstances.

Professor Celli says* all the employés of the Tivoli Railway have been personally examined by him, and all those who have been protected by mosquito-nets have enjoyed an absolute immunity from malarial disease, while those who have not been so protected have all suffered.

An experiment of Professor Grassi's is interesting in this connection†:—He obtained the use of two rooms in a cottage at Maccarese, one of the most malarious villages in the Campagna. The windows were closed with perforated zinc, through which air, but not mosquitos, could pass. Every evening, for eight days, he left Rome, at 5.30, accompanied by a family from the healthiest district of Rome, consisting of father, mother, and five children, varying from one to nine years of age, and passed the night in these rooms, the windows being left open. Professor Grassi took care that none of the family left the rooms between sunset and sunrise; but, about 8 a.m. every morning, he and the family returned to Rome. They had breathed the night air of this intensely malarious spot and drunk the water that they found there; yet twelve days after they had permanently returned to the city, not one of them had been attacked with malaria.

Professor Grassi's results have been so encouraging that the Adriatic Railway, with 6,417 employés, has decided to enforce a rigid mosquito prophylaxis, including mosquito-net protection, fumigation of houses, and the prophylactic use of quinine and

* See *British Medical Journal*, Feb. 10 1900, p. 324.
† See *Ibid.*, Sept. 9 1899, p. 684.

methylene-blue. Other railway companies and commercial bodies in Italy are following suit.

Education.—The scattered literature of malaria consists of an amazing collection of coincidences. Laveran's discovery of the parasite at first only tended to enlarge the collection till the flow of hypothesis and conjecture, turned into the right channel by Manson, was changed for ascertained fact by the discoveries of Ross.

" Unhappily [says Ross*], our efforts to obtain a more scientific frontier of defence against this disease, have always, hitherto, been defeated by our ignorance as to the exact manner in which the infection is produced."

We are now no longer in ignorance, and it behoves medical men in all parts of the world, not only to take an interest in the subject themselves, but to get others to do so, in order that the knowledge already gained may be the sooner turned to practical use.

* *British Medical Journal*, July 1st 1899, p. 1.

EXPLANATION OF PLATES.

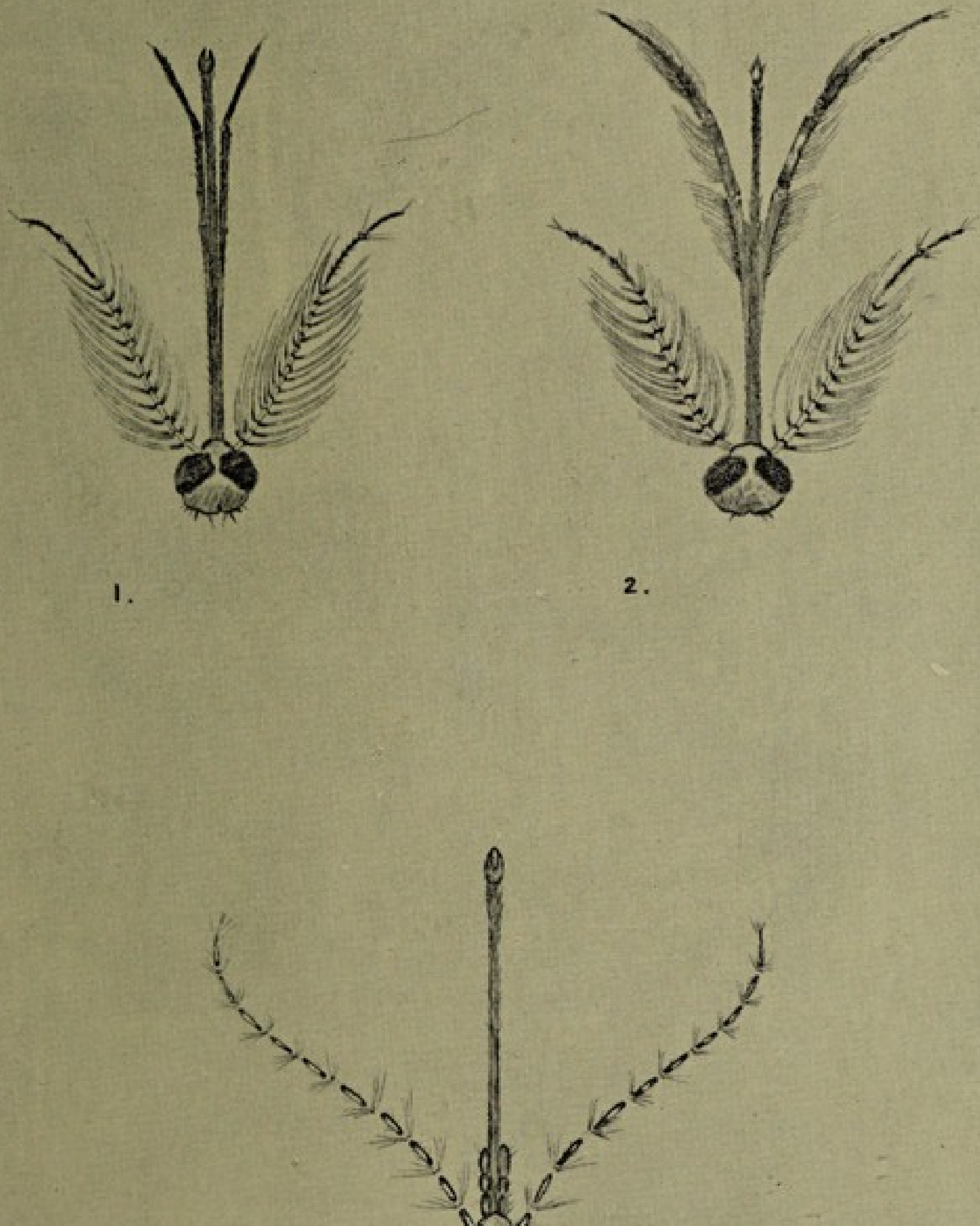
EXPLANATION OF PLATE I.

Fig. 1.—Head of male Culex, showing palpi longer than the proboscis. (Position of parts as in life.) Magnified.

Fig. 2.—Head of male Culex, showing palpi longer than the proboscis and feathered like the antennæ. Magnified.

Fig. 3.—Head of female Culex, showing the very short palpi. Magnified.

PLATE I (*Culex*)



1. 2. 3.

L. N. TASKAR. del.

EXPLANATION OF PLATE II.

Fig. 1.—Attitudes assumed by Culex when at rest on a wall. *a. c. d. e. f. g. h.* females ; *b.* male. (Note posterior pair of legs extended above the body.) Natural size.

Fig. 2.—Female Culex. Natural size.

Fig. 3.—Male Culex. Natural size.

Fig. 4.—Female Culex. Enlarged.

Fig. 5.—Female Culex, with eggs fully developed.

Fig. 6.—Male Culex, with palpi and antennæ feathered.

Fig. 7.—Eggs of Culex in black boat-shaped masses. (The left-hand figure in the test-tube shows the larvæ just hatching out into the water.) Natural size.

Fig. 8.—Egg-boats seen from above. Natural size.

Fig. 9.—Eggs ; side and end views. Enlarged.

Fig. 10.—Nymphæ. Natural size

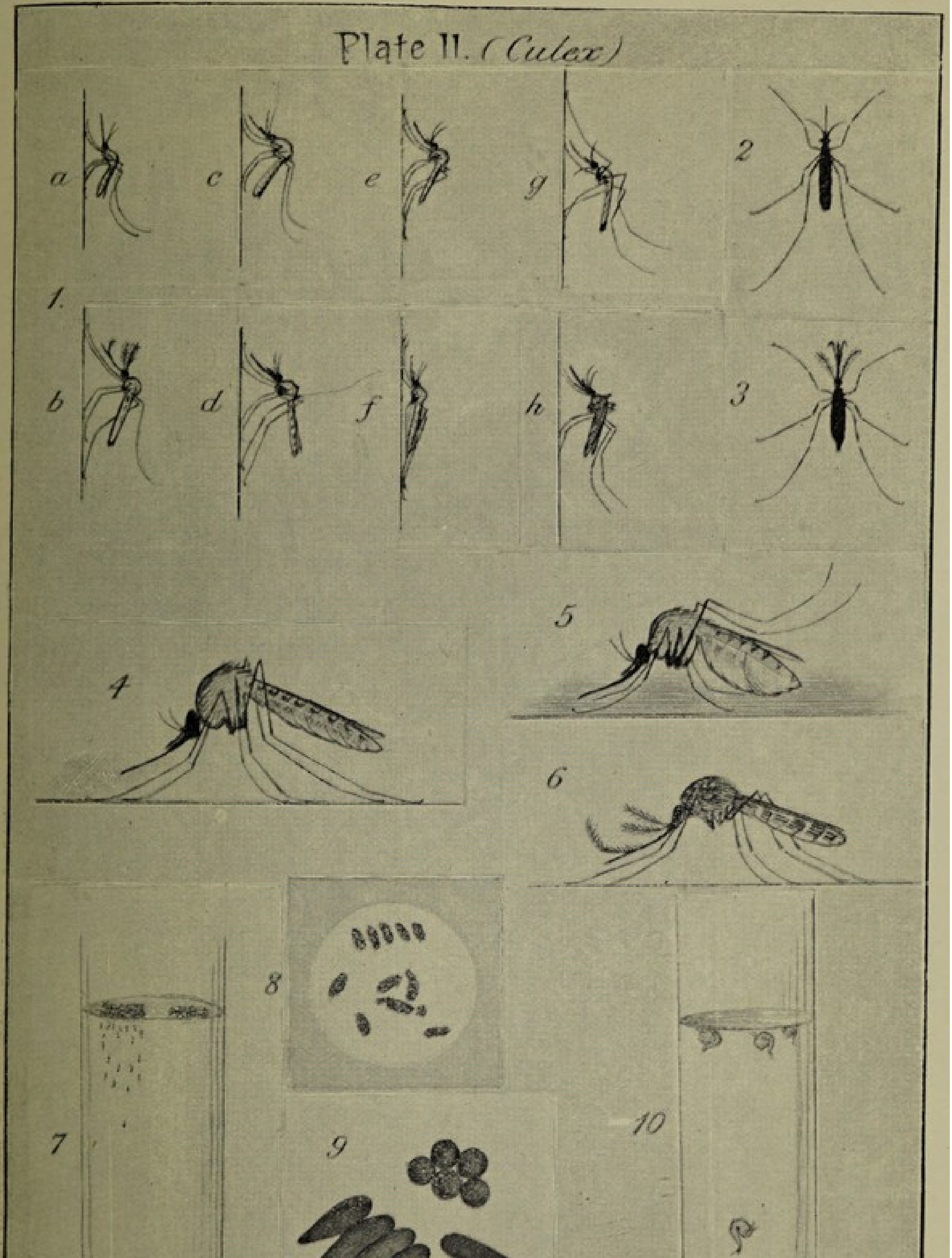


Plate II. (Culex)
a
c
e
g
2
1.
b
d
f
h
3
5
4
6
8
7
9
10
C. Christy. del.

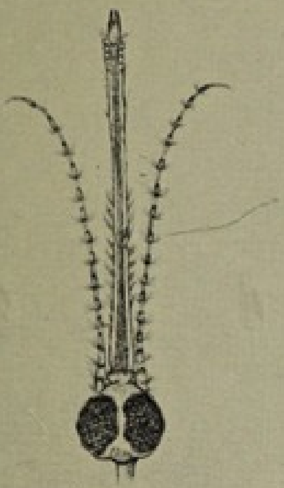
EXPLANATION OF PLATE III.

Fig. 1.—Head of female Anopheles, showing palpi about same length as proboscis. (Position of parts as in life.) Magnified.

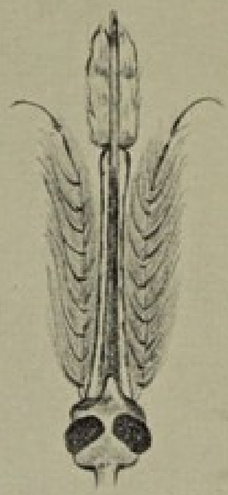
Fig. 2.—Head of male Anopheles, showing palpi about same length as proboscis and clubbed. (Position of parts as in life.) Magnified.

Fig. 3.—Head of female Anopheles. Parts separated to show the large hypodermic-needle-like central stylet of the proboscis; two pairs of fine hair-like stylets which, in life, lie along the central stylet (function of these stylets doubtful); the proboscis or sheath, open on its under surface, for the reception and protection of the central and the two pairs of hair-like stylets; the two palpi; and the two antennæ. All magnified.

PLATE III (*Anopheles*)



1



2

3

L.N. TASKAR *del.*

EXPLANATION OF PLATE IV.

Fig. 1.—Attitudes assumed by Anopheles when at rest on a wall. *a. b. c.* males; *d. e.* females; *f.* female lifting palpi and antennæ whilst in the act of probing. (Note posterior pair of legs extended beneath the body.) Natural size.

Fig. 2.—Female Anopheles. Natural size.

Fig. 3.—Male Anopheles. Natural size.

Fig 4.—Male Anopheles in the act of probing. Natural size.

Fig. 5.—Female Anopheles. Enlarged.

Fig. 6.—Eggs of Anopheles, floating in a test-tube. Natural size.

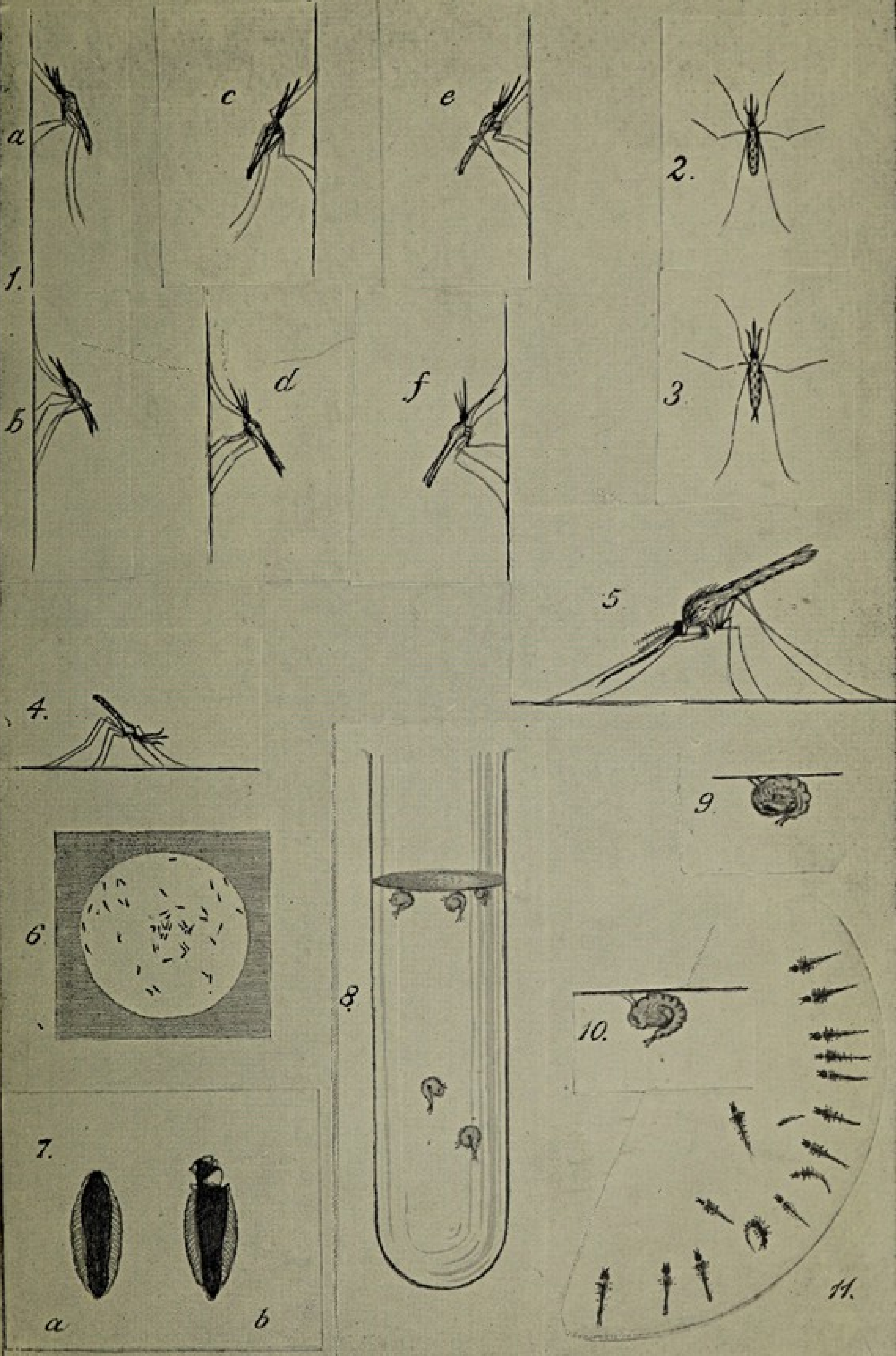
Fig. 7.—Eggs of Anopheles. *a.* unhatched; *b.* hatched-out shell. Much enlarged.

Fig. 8.—Nymphæ or Pupæ. Natural size.

Figs. 9-10.—Nymphs. Enlarged.

Fig. 11.—The larvæ of Anopheles floating in the water of a tumbler. Natural size.

Plate IV. (*Anopheles*)



C. Chrisly. del.

EXPLANATION OF PLATE V.

Fig. 1.—Anopheles larva, drawn under $\frac{3}{4}$ inch lens.

Fig. 2.—Posterior end of Anopheles larva, looking from above, showing openings of tracheæ.

Fig. 3.—Posterior end of Anopheles larva; side view, showing position of tracheæ.

Fig. 4.—Larvæ of Anopheles in test-tube. Natural size.

Figs. 5-6.—Larvæ of Anopheles in position of rest at surface of water. Magnified 6 diams.

Fig. 7.—Culex larva (young). Enlarged.

Fig. 8.—Culex larvæ in test-tube. Natural size.

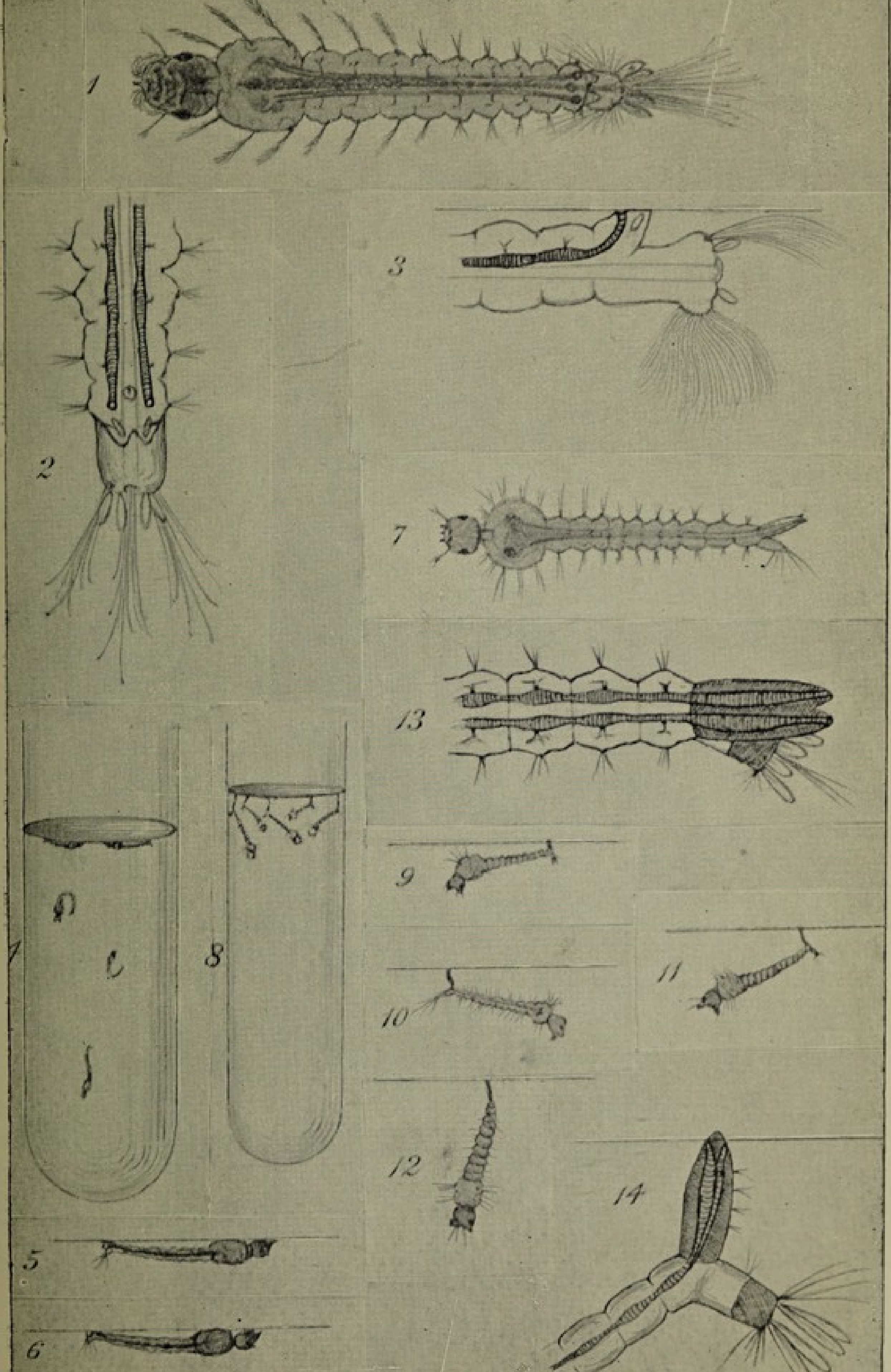
Figs. 9-10.—Culex larvæ, showing position of rest at surface assumed by some species. Enlarged.

Figs. 11-12.—Culex larvæ, showing the usual position of rest at the surface assumed by most species. Enlarged.

Fig. 13.—Posterior end of Culex larva, looked at from above, showing the black buoy-like prolongation at the end of which the tracheæ open.

Fig. 14.—Posterior end of Culex larvæ; side view, showing position of tracheæ and the fussiform dilatations.

Plate V. (*Larvæ*)



INDEX.

Aedes, 31.
Æstivo-autumnal fever, 3, 26, 49, 54.
Africa, West, see West Africa.
Altitude and malaria, 57.
America, South, malaria in, 56; mosquitos of, 55, 56.
Anatomy of mosquitos, 12, 19.
Anopheles, 21, 31, 49, 59; attitude of, 32, 39; and black spores, 24; bite of, painless, 32, 39, 40; breeding places of, 36, 37, 44, 45, 52, 57, 58, 59, 60, 63; bites of, exposure to, 25, 26, 28; description of, 31, 32, 39; development of parasite in, 27; differs from Culex, 31, 32, 39, 40; digests blood quicker than Culex, 41; distribution of, 55, 59; epidemic fostered by, 52, 53; extermination of, 44, 47; gathers where people congregate, 54; hatching out of, and prevalence of fever, 51; infection by, 26, 27, 28; larvæ of, see Larvæ; life history of, 30; muteness of, 32, 39, 40; nymphæ of, see Nymphæ; on ships, 61; one species carries three types of fever, 27; only malaria-carrying genus, 29, 44; ova of, see Ova; pigmented cells in, 53; position on wall of, 32, 39; reproduction of, 43; sex of, 40; time of biting of, 40, 41; transmission of parasite in, 28; in West Africa, 42, 51, 59; see also Mosquitos.
Attitude of Anopheles, 32, 39.
Bancroft, on feeding of larvæ, 41.
Bastianelli, 25, 26; and Bignami, Anopheles gathers where people congregate, 54.
Bignami, experiments on human inoculation, 25, 26; see also Bastianelli.
Bird malaria, parasite of, 9, 20; investigations of, 8, 9, 10, 11.
Biskra, 56.
Bite of Anopheles painless, 32, 39, 40.
Bites, exposure to mosquito, 25, 26, 28.
Biting-time of Anopheles, 40, 41; of Culex, 41.
Black spores, see Spores, black.
Breeding places of mosquitos, 36, 37, 44, 45, 52, 57, 58, 59, 60, 63.
Brindled mosquito, 8, 21.
Campagna, a malarial district, 1, 28, 54.
Casagrandi, 25; and Celli, on larvicidal and culicidal substances, 46, 47.
Celli, 25; on the sources of infection, 29; on the reproduction of Anopheles, 43; on the relation of malaria to seasons, 49; on temperature and malaria, 50; on artificial immunity, 61; on isolation, 65; see also Casagrandi.
Châtillon-sur-Loing, 48.
Classification, of malaria parasite, 2; of mosquitos, 30, 31.
Coccidia, 17, 53; derived from ingested proteosomata, 16; development of, 15, 18, 22; sporulation of, 16, 17, 19.
Coccidiidæ, 2.
Collection of mosquitos, 31.
Corethra, 40.
Crescents, 7, 8, 10, 14, 60, 64.
Culex, 21, 31, 44, 52; breeding places of, 36, 58; description of, 32, 33, 39; how it differs from Anopheles, 31, 33, 39, 40; digests blood more slowly than Anopheles, 41; feeds on cattle, 58; human malaria not conveyed by, 29, 52; larvæ of, see Larvæ; nymphæ of, see Nymphæ; ova of, see Ova; position on wall of, 32, 33, 39; sex of, 40; time of biting of, 41; see also Mosquitos.
Culicidæ, classification of, 31.
Culicidal substances, 47.
Dapple-winged mosquito, 7, 8, 21, 26.
Daniels confirms Ross's experiments, 22; investigations of black spores and striated bodies, 22, 23.

Deserts and malaria, 56.
Desiccation of Anopheles larvæ and ova, 30. 43
Destruction, of Anopheles larvæ, 44, 45 ; of mosquitos, 47.
Development, of coccidia, 15, 18, 22 ; of mosquitos, 30 ; of pigmented cells, 12, 13, 14.
Dissection of mosquitos, 11.
Distribution, of Anopheles, 55, 59 ; of mosquitos, 25, 55, 59.
Drainage, effects of, 45.
Drinking-water and malaria, 5, 16, 23 24, 55, 61, 65.
Duckweed and Anopheles larvæ, 37.
Dust, infection by inhalation of, 5, 23, 54, 55.
Dutch Indies, German expedition to, 61.
Elephantiasis, 5.
Epidemics of malaria, 52, 53, 54 ; fostered by Anopheles, 52, 53.
Experiments of Ross, on bird malaria, 8, 9, 10, 11 ; on feeding mosquitos on malarial blood, 7, 8.
Extermination, of Anopheles, 44, 47; of malaria in Lincolnshire, 45.
Fecundation of mosquitos, 42.
Fever, æstivo-autumnal or remittent, 3, 26, 49, 54 ; malarial, conveyed by a single bite, 27 ; development of epidemics of, 52, 53 ; epidemic, course of, 49 ; maximum occurrence of, 50, 51 ; mortality from, 44 ; propagated by Anopheles, 28, 29, 51, 52 ; recurrence of, 29 ; three types of, 3, 27, 49 ; severe in children, 61 ; quartan or three-day, 3, 27, 49 ; tertian or two-day, 3, 27, 49 ; see also Malaria.
Ficalbi, his classification of mosquitos, 31.
Filaria, 5.
Fish and mosquito larvæ, 37, 58.
Flagella, 3, 17, are spermatozoa, 6 ; develop in mosquito, 4.
Gametocytes, 3, 7 ; are sexual forms, 6, 17.
Geographical distribution, of mosquitos, 25, 55, 59 ; of malaria, 55.
Germinal threads, 18, 19, 22, 23, 24.
Grassi, 25, 26 ; on distribution of mosquitos, 25 ; discoveries by, 26 ; exposed to Anopheles bites, 28 ; on Anopheles larvæ and Lemna, 37 ; on time of biting of Anopheles, 40, 41 ; on time of biting of Culex, 41 ; his experiments on isolation, 65.
Grellet, effect of lime on malarious soil, 48.
Grey mosquito, 8, 9, 10, 11, 17, 20, 21, 27, 31.
Grosseto, Tuscany, 50.
Habitat, of Anopheles larvæ, 36, 37, 40 ; of Culex larvæ, 36, 40.
Halteridium, 9, 10, 11, 13, 20.
Hankin, on diet of Culex larvæ, 36.
Hibernation of mosquitos, 43, 61.
Hong Kong, malaria in, 52.
Human malaria, not conveyed by Culex, 26 ; parasite similar to that of bird, 20 ; see also Malaria.
Immunity, artificial, 61 ; distance necessary to secure, 60 ; from methylene blue, 61 ; work of Koch on, 61.
India, non-malarious areas in, 57.
Indies, Dutch, see Dutch Indies ; West, see West Indies.
Infection, carried by Anopheles, 26, 27, 28 ; by drinking water, 5, 16 23, 24, 55, 61, 65 ; experimental. of birds, 20 ; experimental, of man, 25, 26 ; by inhaling dust, 5, 23, 54, 55 ; by injection of malarial blood, 59 ; the sources of, 29.
Inoculation by mosquito bites, 25, 26 ; experiments on, 59.
Insect bites, diseases conveyed directly by, 5, 27.
Insects as extra-corporeal hosts, 5, 28.
Isolation, 64.
James, Dr S. P., on Anopheles larvæ in rice fields, 37.
Jasalmir State, India, 57.
Kilborne and Smith on Texan cattle-fever, 27.
King, his mosquito theory, 5.
Koch, on bird malaria, 9 ; on similarity of bird and human parasite, 20 ; on the black spores, 24; his experiments on inoculation, 59 ; on immunity, 61 ; on malaria in children, 61.
Labbé, on bird malaria, 9.
Lagos, West Africa, 50.
Lancisi, his theory of malaria, 2.

Larvæ, of Anopheles, 28, 41, 44 ; description of, 33, 34, 39, 40 ; desiccation of, 30, 43 ; destruction of, 44, 45, 46, 47 ; diet of, 34, 36 ; fish and, 37, 58 ; habitat of, 36, 37, 40 ; and Lemna, 37 ; in rice fields, 37 ; of Culex, description of, 35, 39, 40 ; diet of, 36, 41 ; habitat of, 36, 40.
Larvicidal substances, 45, 46.
Latent phase of the parasite, 29, 60.
Laveran, 2, 66.
Lemna and Anopheles larvæ, 37.
Life history of mosquitos, 30.
Lime, effect on malarious soil of, 48.
Lincolnshire, malaria exterminated from, 45.
Literature of malaria, 65.
MacCallum, discoveries by, 6 ; his work on bird malaria, 9.
Maccarese, Italy, 26
Malaria, altitude and, 57 ; of birds, see Bird malaria ; contracted near houses, 59 ; contracted near water, 55, 58, 60 ; conveyed by mosquitos, 1, 20, 24, 26, 29, 39, 44 ; deserts and, 56 ; diminishes with age, 62 ; distribution of, 55 ; distribution of Anopheles and, 59 ; disturbance of soil and, 51, 52, 54 ; drinking water and, 5, 16, 23, 24, 55, 61, 65 ; dust and, 5, 23, 54, 55 ; exterminated from Lincolnshire, 45 ; geographical range of, 55 ; isolation and, 64 ; literature of, 65 ; morasses and, 55, 58, 59, 60 ; parasite, see Parasite ; quinine and, 64 ; rains and, 50, 51 ; range of, 55 ; in Sahara, 56 ; sanitation and, 63 ; seasons and, 49, 50 ; on board ship, 61 ; soil and, 5, 29, 48, 51, 52, 54 ; swamps and, 55, 58, 60 ; temperature and, 50 ; water and, 4, 5, 16, 23, 24, 29, 55, 58, 60, 61, 65 ; winds and, 60 ; see also Human malaria and Fever, malarial.
Malaria, Epidemic of, 52, 53, 54 ; fever, see Fever ; pigment, see Pigment.
Malarious soil, effect of lime on, 48.
Manson, Dr. Patrick, 17, 66 ; on the malarial parasite, 2, 4, 5 ; on Filariasis, 5 ; observations on discovery of malarial pigment in mosquitos, 7 ; announces Ross's work, 25 ; on malaria and disturbance of soil in Hong Kong, 52 ; on geographical range of malaria, 55 ; on malaria in Sahara, 56 ; on distance necessary to secure immunity from malaria, 60.
Methylene blue and immunity, 61.
Miasmas from marshes, 60.
Morasses, and malaria, 55, 58, 59, 60.
Mortality from malaria, 44.
Mosquitos, anatomy of, 12, 19 ; brindled, 8, 21 ; brown-brindled, 8 ; certain species correspond with malarial districts, 25 ; classification of, 30, 31 ; collection of, 31 ; convey malaria, 1, 20, 24, 26, 29, 39, 44 ; dapple-winged 7, 8, 21, 26 ; destruction of, 47 ; development of, 30 ; dissection of, 11 ; distribution of, 25, 55, 59 ; exposure to bites of, 25, 26 ; fecundation of, 42 ; feeding of, 11, 40, 41, 42 ; and Filariasis, 5 ; fish and, 37, 58 ; grey, 8, 9, 10, 11, 17, 20, 21, 27, 31 ; hibernation of, 43, 61 ; life history of, 30 ; will live for eight weeks, 43 ; morasses and, 58 ; in Norway, 43 ; can pass through netting, 32, 42 ; sex of, 40 ; South American, 56 ; will suck blood from a corpse, 42 ; swamps and, 58 ; see also Anopheles, Culex, Larvæ, and Nymphæ.
Muteness of Anopheles, 32, 39, 40.
Niger River, 58.
Nigeria, 42.
Norway, mosquitos in, 43.
Nymphæ, of Anopheles, 37, 40, 42 ; of Culex, 37, 40, 42, 43
Ostia, Italy, 54.
Ova, of Anopheles, 33, 39 ; desiccation of, 30, 43 ; of Culex, 33, 39.
Pacific Islands, South, 56.
Palpi of mosquitos, length of, 31, 39.
Parasite, the malarial, 2 ; its development in suctorial insect, 4 ; discovery of, 2 ; two forms of, 3 ; importance of, 2 ; intra-corpuscular, 2, 3 ; latent phase of, 29, 60 ; its non-transmission from parent to offspring, 28 ; zoological classification of, 2.

Parasites possessing double life-cycle, 2.
Pfeiffer, on parasites with double life-cycle, 2.
Pigment, malarial, 27 ; discovered in mosquitos by Ross, 7.
Pigmented cells, 7, 8, 17 ; in Anopheles, 53 ; development of, 12, 13, 14 ; in grey mosquitos, 9 ; and proteosomata, 10.
Proteosoma, 9, 10, 11, 13, 15, 16, 17, 19, 20, 23 ; coccidia derived from ingested, 16 ; cultivability of, 17 ; propagation by rest spores, 23, 24 ; proteosoma-coccidia, 15 ; see also Coccidia.
Pupa, see Nympha.
Quartan fever 3, 27, 49.
Quilon, Travancore, 37.
Quinine, action of, 3, 64.
Rains and malaria, 50, 51.
Remittent fever, 3, 7, 26, 49, 54.
Reproduction of Anopheles, 43.
Rest spores, see Spores, black.
Rice-fields and Anopheles larvæ, 37.
Rome, 1, 26.
Ross, he discovers flagella in mosquitos, 4 ; he discovers malarial pigment in mosquitos, 7 ; experiments on feeding mosquitos on malarial blood, 7, 8 ; his experiments on bird malaria, 8, 9, 10, 11 ; on development of pigmented cells, 12, 13, 14 ; on development of coccidia, 15, 18 ; on sporulation of coccidia, 16, 17, 19 ; he describes black, sausage-shaped bodies in coccidia, 16, 18 ; describes striated appearance in coccidia, 16, 18 ; on infection of healthy birds, 20 ; work announced by Manson, 25 ; on one species carrying three types of fever, 27 ; on former ignorance, 66.
Sahara, malaria in, 56.
Salivary gland of mosquito, 19, 26, 35.
San Domingo, 56, 57.
Sanitation and malaria, 63.
Santo Spirito hospital, 28.
Santori, 25.
Sarrasin, on Celebes, 59.
Seasons and malaria, 49, 50.
Sex of mosquitos, 40.
Ship malaria, 61.
Ships, Anopheles on, 61.
Sierra Leone, 27 ; expedition to, 32, 58.
Simond, on parasites with double life-cycle, 2.
Smith and Kilborne on Texan cattle-fever, 27.
Soil, effect of lime on malarious, 48 ; malaria, a disease of the, 5, 29 ; malaria and disturbance of, 51, 52, 54.
South America, see America, South.
Spores, black, and Anopheles, 24 ; described by Ross, 16, 18 ; investigated by Daniels, 22, 23 ; propagation by, 23, 24 ; resistance of, 23 ; significance of, 23, 24.
Sporocytes, 3.
Sporozoa, 2.
Sporozoites, 26, 54.
Sporulation of coccidia, 16, 17, 19.
Strachan, Dr., on rains and malaria, 50, 51
Striations of coccidia, described, 16, 18 ; investigated, 23 ; significance of, 19, 20.
Sutton, Dr. J. Bland, 7.
Swamps, malaria contracted near, 55, 58, 60.
Temperature and malaria, 50.
Tertian fever, 3, 27, 49.
Texan cattle-fever, 5, 28.
Theory of King, 5 ; of Lancisi, 2 ; of Manson, 4 ; of propagation by rest-spores, 23, 24.
Thin, Dr., 7.
Threadlike bodies, see Germinal threads.
Trees harbour mosquitos, 63.
Tsetse-fly disease, 5.
Water and malaria, 4, 29, 58, 60 ; see also Drinking-water.
West Africa, Anopheles in, 42, 51 59.
West Indies, malaria and mosquitos in, 56.
Winds and malaria, 60.
Veneno-salivary gland, 19, 26, 53.
Zoological classification of mosquitos, 30, 31 ; of the malaria parasite, 2.
Zygotoblasts, 27, 53 ; see also Germinal threads.
Zygotes, 6, 17, 27, 53.

WELLCOME LIBRARY INSTITUTE