"THE PROPHYLAXIS OF MALARIA IN THE SUDAN".

BEING A THESIS PRESENTED FOR THE DEGREE OF M.D.

OF GLASGOW UNIVERSITY.

by

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SEEDLEY,

MANCHESTER. May 1909.

Gentlemen,

Of late years the subject of Malaria, with special reference to its causation, prevention, and cure has received the attention of many distinguished scientists. It is therefore with deference that I presume to present my quota of observations on a section of the subject in a practically new Country.

Since the discovery of the parasite in 1880 by Laveran, the literature on the subject has become quite imposing, and the life history of the parasite in man and mosquito, and of similar parasites in birds, has been fully investigated in a brilliant and scientific manner by numerous observers. Golgi first demonstrated the relationship between the segmentation of the parasite and the occurrence of fever in 1885, and to Ross we are indebted for the knowledge of the sexual cycle in mosquitoes. Ross first worked out this cycle in 1897 with proteosoma in birds, and a year later Grassi and Bignami demonstrated a similar cycle in the true malarial parasites. Since then the work has been carried on and expended by others till, at the present day, malaria is a disease the knowledge of which is based on the soundest scientific facts.

I held the post of Medical Officer to a large Plantation in Berber Province, Sudan, and although Malaria formed fifty per cent of the illness which I had to treat, still my time for its study was limited; I arrived to find things in a hoplessly insanitary state, the most perfect conditions for the breeding of Mosquitoes and ~~that~~, in addition to medical and surgical work, I had to see to the sanitation, to the veterinary work, and to the destruction of locusts. The community under my charge including workmen and their families, and natives dwelling within a radius of ten miles or more, totalled

7000 to 8000 souls. I had a small Hospital and a room which I used as a Laboratory, but my equipment was somewhat crude. Sand percolated (permeated) everything, and the climate spoiled the films, stains, and the temper of the investigator. I had no trained assistants and naturally my hands were somewhat full.

I propose to limit myself in this article to observations on the prophylaxis of malaria in the Sudan, together with some notes on immunity.

The subject resolves itself into the study of the mosquito problem, and the administration of quinine in some form in sufficient doses to prevent the development of the malarial parasite in the human subject. If malaria-carrying mosquitoes can be exterminated in a district there is no need for the administration of quinine to the inhabitants as a prophylactic.

PREVALENT CONDITIONS.

In the first place let us consider the climatic, topographical, sanitary, agricultural, and entomological conditions prevalent, for these all have a bearing on malaria.

Climatic and Meteorological Conditions. The climate of Berber Province is somewhat trying to the white races. The heat is intense for the greater part of the year, but the low humidity of the atmosphere makes the heat more endurable. In summer the day shade temperature is commonly about 110° F., and on one occasion I found that the thermometer registered 118° F. in the shade. The minimum night temperature varies, but 80° F. to 85° F. is of common occurrence. December, January, and February are the coolest months of the year, when the maximum shade temperature varies from 70° F. to 75° F, and at night the temperature commonly falls as low as 40° F. to 45° F. The chilly nights and early mornings of winter serve as a stimulus to the resident whites, but play havoc with the

Temperature.

poorly clad natives. They are frequent victims of pneumonia, pleurisy and catarrhal colds, and their lowered resistance is evidenced by the occurrence of latent malaria and the frequency of new malarial infections among them.

Rain. Rain occurs in occasional showers, often torrential, in June, July, and August, although it infrequently is known earlier or later in the season. In 1907 most rain occurred in August, when it was excessive. I remember a shower lasting five hours which practically flooded the whole Plantation, spoiled crops, washed down mud houses, and carried trees and animals away in the rain "Khors". After rain, although the temperature falls, the great increase in the humidity of the atmosphere makes the heat feel just as great and certainly more exhausting. It is at this period of the year that Europeans have their body resistance lowered and illness becomes rife among them. Surface pools left after rain favour mosquito breeding, but I did not find this so prevalent as I expected. It was only in rain pools which had not dried up in two or three weeks that mosquito larvae were found. Perhaps it is only after the growth in the pools of minute vegetable organisms that conditions are produced suitable to the growth of mosquito larvae. Of course the parched condition of the soil and the high temperature of the atmosphere favour the rapid drying up of the pools, and on the whole the increase in the number of mosquitoes from rain pools is inconsiderable compared to that from other causes mentioned later.

Winds. The prevailing winds are S.S.W. in the summer and N.N.E. in the winter. Sand storms or "haboubs" occur most frequently in summer; they come on suddenly and may last for a few minutes or many hours. (Fig. 1.) They frequently occur at night and cause sleepless nights and much incon-

Fig.1. Sandstorm. (From a photo by Dr.Beam in 2nd Report Wellcome Research Laboratories)

Fig.2. - River Nile.

Fig.3. - RiverAtbara, showing mosquito breeding pool.

venience. The loss of sleep occasioned by "haboubs" and, biting insects no doubt materially assists the continued exposure to the great heat and light of the sun in producing the tropical neurasthenia and lowered vitality which predispose white residents to malaria and other diseases.

Topography. Berber Province consists of an immense tract of arid desert with one large river passing through it. This river, the Nile, is the saving grace of the Country, and it is only in its vicinity that animal and vegetable life are found. (Fig.2.) The river Atbara is its only tributary worthy of mention but it is stagnant and in places dry for several months each year. (Fig.3.) In the southern Sudan conditions are different. There we have the White Nile and the Blue Nile, the latter by draining the rains of Abyssinia producing the bulk of the Nile flood which is of so much importance to the Sudan and to Egypt. Tributaries of these are numerous and the Country contains much vegetation varying in nature in different localities. However it is mainly with the conditions between Khartum and Atbara that I have to deal.

Along the banks of the Nile there is a continuous growth of date palms, dome palms (their fruit is known as vegetable ivory), many varieties of thorny leguminous trees, and a profusion of "ushar" plants or Sodom apple plants (Calotropis procera). As one recedes from the river the vegetation gets more sparse and the trees more stunted according as the soil level becomes higher. In places where there is a natural basin where rain water can collect, vegetation is continuous for several miles out, (Fig.4.) but where the level rises rapidly, a few hundred yards from the river there may be no sign of vegetation.

"Wadies". Many miles out in the desert in natural hollows where rain collects, stunted bushes and grass are found.

(a)

(b)

(c)

Fig.4. - Vegetation: (a) on river bank; (b) several miles from river; (c) clearing same.

Fig.5. - "Wadies", 30 miles from river, where maize is grown.

The grass soon dries up in the dry season, but the trees have roots penetrating deeper in the soil enabling them to reach sufficient moisture to keep them alive till the following rainy season. These shallow natural hollows or "wadies" and the water courses or "Khors" emitted from them are of much economic and scientific interest. Every year after rain the natives plant "durrha", a variety of maize (sorghum), in the moist soil of these wadies. Thus without the labour of ploughing or irrigation they get sufficient maize to keep them in bread. One would expect that the pools of water in these wadies would be suitable breeding places for mosquitoes. However there is only water there for a few weeks each year, and it is many miles from the usual haunts of mosquitoes. Natives told me that there were no mosquitoes at the wadies, and although several natives returned from them suffering from malaria it was probably due to recurrences of old infections. I paid a visit to several wadies twenty to thirty miles out from the river, but all the pools had dried up, (Fig. 5.) and I found no mosquitoes, although owl midges were in sufficient numbers to cause annoyance. In the water courses emitted from the wadies, pools were left for several weeks, and where these occurred in the mosquito zone they formed additional breeding places, and required considerable attention to keep them free from mosquito larvae.

"Khors". By the annual rise of the Nile other water courses or "Khors" are formed by the river overflowing its banks and following the line of least resistance and of gravity. (Fig. 6) The Country all along the left bank of the Nile is cut up by these "Khors" which at high Nile are flowing rivers and at low Nile are dry, and in them, at one time of the year, pools are left suitable for the breeding of mosquitoes. Then again, pools are left on the main banks of the river during its fall where the slope of the banks is

Fig.6. - "Khor".

Fig.7. - Pools on Blue Nile at low river, where
Anophelines bred out.
(From photo in 2nd Report Wellcome Research Laboratori

gradual. (Fig.7).

We have thus four great natural means of production of mosquito breeding places:-

(1). Khors formed by the high Nile.

(2). Pools left on the sloping banks of the falling Nile.

(3). Rain Khors flowing from wadies.

(4). Ordinary surface rain pools. (Fig.8).

These occur annually and cannot be prevented. They thus form the most difficult part of dealing with the mosquito problem. They can be modified however, by attention to them, where they occur sufficiently near populous districts to be a danger to the community. This can only be done at great expense by the formation of mosquito brigades to drain or fill up hollows containing stagnant water, to deviate the course of Khors, and to treat water with larvicides where other means are not available. Other numerous breeding places are produced artificially by man in faulty irrigation and careless methods of obtaining, storing, and disposing of water. These will be dealt with later.

Trees. The presence or absence of trees appears to have a considerable effect on the distribution of mosquitoes and hence of malaria. If mosquitoes are bred in well wooded situations they seem to stick there with great tenacity. Our main living quarters at the Plantation unfortunately gave ample evidence of this fact. The houses were situated in a large garden of some five acres in extent and having many trees in and around it. This garden was irrigated by a small canal and subsidiary ditches, and so plenty of water was scattered about favourable to mosquito breeding. (Fig.9). To this area I gave special attention, and by the free use of petroleum and the running of the canal dry at frequent intervals, mosquito breeding was

Fig 8. - Rain pools in Khartum.
(From a photo in 2nd Report Wellcome Research Laboratories

(a)

(b)

Fig.9. Garden. (a) Showing faulty irrigation and breeding pools for mosquitoes
(b) Showing proximity of trees which harboured mosquitoes.

fairly well prevented. Unfortunately however, the garden adjoined the cultivated land, several thousand acres of which were irrigated and could scarcely be efficiently treated with the limited means at my disposal. To add to the difficulty, the prevailing wind blew ~~straight~~ across this large irrigated area straight into the garden and there was no protecting border of trees on the side of the cultivated land. We thus had an excellent trap for retaining mosquitoes in our midst. The strong winds which frequently occurred, rising suddenly and dying away as suddenly, although they seemed at times to bring half the desert sand with them and obscured the sun, and were quite capable of overturning tables and beds, seemed to utterly fail to dislodge the mosquitoes from their retreats among the trees. In fact they brought great numbers from the more open farm and lodged them safely for our annoyance among our garden trees. Some authorities advocate the formation of a dry belt for a mile outside towns in malarial districts, so that mosquito breeding cannot take place in that dry belt and anophelines will not fly a mile unaided by wind. This is certainly good practice but I should advocate, where practicable, a belt of trees outside this area to act as a screen preventing mosquitoes being blown across the dry zone to the town. The pumping station where the engineers, firemen, and about a hundred labourers and their families lived exemplified the benefit of such a tree zone. Between the cultivated land and the pumping station there was a belt of thick scrub and trees, and although the prevailing wind was from the cultivation to these quarters, and there were at the quarters pools of water suitable for mosquito breeding, these pools were only found infected on four occasions during a year of repeated examination. On the same side of this tree belt as the pumping station, and within half a mile of it, was a native

"Dry Belts".

Tree Belts.

village situated at the mouth of a Khor where the usual breeding pools were formed. It was during a time of year when the prevailing wind was from this direction that the pools at the pumping station were found infected. This would go to show that the tree belt practically acted as a screen to mosquitoes being blown off the cultivated land to the pumping station, and also that the mosquitoes developed in the Khor pools did not as a rule fly the half mile to the pumping station unless when assisted there by wind.

<u>Sanitary Conditions.</u> The average Sudanese village is absolutely devoid of any organised means of dealing with waste matters, animal and human excreta, and other nuisances. Nature steps in and supplies a powerful germicide, the sun. The enclosure in front of each individual hut is occasionally swept clean of unsightly refuse, but this is deposited at the nearest possible spot out of direct vision. Latrines are unknown in most villages and indiscriminate defaecation in and around villages is common. The ground soon becomes heavily laden with organic matter which in the rainy season may easily be washed into wells used for drinking purposes. The butcher kills his sheep or bullocks under a tree as nearly as possible in the centre of the village. He thus avoids the necessity of carrying the carcases to the village, and the more central his stall the less distance have his customers to walk. The blood and faeces of the slaughtered animals soak the ground around the tree, and an excellent medium for the growth of micro-organisms is formed, especially in the rainy season when additional moisture encourages putrefaction. Expectoration is rife in and around houses. The excreta of sick people are deposited on the floor. It is so easy to cover these things on a mud floor with a little sand from outside the door. These practices, carried on to the extent they are, would soon lead to numerous epidemics, but Father Sol prevents that. At times he has a hard fight, as when a

dead dog is left to rot within fifty yards of a clump of houses; but he conquers in the end and makes a very good work of bleaching the bones a beautiful white.

Conservancy System. In towns used as Government Headquarters a latrine system of dry buckets containing sand and emptied daily is in vogue. This system I instituted at the Plantation with satisfactory results. The butcher was compelled to kill well outside the village, and all garbage and animal excretions were collected daily from the village and removed by cart to a suitable place.

Wells. Most villages have several wells for drinking purposes. When in regular daily use these are seldom found infected with mosquito larvae. However a few disused wells can generally be found, and they are frequently teeming with mosquito larvae, usually culices, I admit, but occasionally with anophelines.

"Zeers". Most native houses contain one or two "zeers" (Fig. 10.) These are porous earthenware vessels of various sizes in which water is kept. By filtration and evaporation the water is kept cool and they form moderately efficient filters. They also form an excellent means of cooling bottled drinks, the bottles being placed inside the cold water. The water of zeers used for this purpose is thus frequently disturbed but nevertheless mosquito larvae may be found in them. I have found anopheline larvae in them occasionally, although it is not what one would expect from their breeding habits. It is well to have these vessels emptied and cleaned every five or six days and so prevent mosquitoes breeding in them. In native houses they are seldom emptied and so are often breeding places for mosquitoes. They are frequently placed at intervals on the public highway for the convenience of the thirsty traveller and (?) for the gravid female mosquito.

Agricultural Conditions. Cultivation with its attendant necessary irrigation and its consequent liability to the

Fig.10. - "Zeer".

Fig.11. - "Sakia" on Nile bank.

formation of mosquito breeding pools is indeed a difficult problem. One naturally cultivates for profit, and if the prevention of malaria is to be obtained at a cost which will take away all profit, one cannot be blamed for leaving the prevention of malaria severely alone. The irrigation system will be dealt with in detail later, but it may be well to mention here that all large plantations in the Sudan are irrigated by a system of canals supplied with water from the river by powerful pumps. Some plantations have in addition a flood canal. This is a canal brought to the plantation from many miles up the river. The mouth of the canal must be higher than the level of the land on the plantation. When the river is high water flows into this canal and irrigates the lower lying plantation or part of it. It can be easily understood that in any canal system dealing with a large volume of water stagnant pools may be formed by leakage, inefficient levelling, and other causes. Irrigation by native methods is much less responsible for mosquito breeding. Not having powerful steam pumps capable of dealing with thousands of gallons of water daily the natives avoid any indiscriminate throwing of water about. They cultivate the land in small patches each supplied by a "sakia". This consists of a roughly made wooden water wheel, worked by oxen, and which raises water in earthenware vessels and empties it into a gutter communicating with the irrigation channels. (Fig. 11). These channels are small being generally about 1 to 2 feet wide and about 6 inches deep. They have a good "fall" and pools are not left in them. It is a fairly easy matter to adjust the levels of a small sakia patch so that no waste pools of water are left. Water is sometimes raised by "shadoofs", a method entailing even greater expenditure of time and labour. The sakias on the river banks are almost harmless as regards mosquito breeding. Sometimes larvae are found in the earthenware vessels

Irrigation.

Flood Canals.

Native Methods.

"Sakias".

containing water, if not in use for several days, but these are generally sullices. However, the large wells where sakias work inland are fruitful sources of trouble. The sakias do not work regularly, with the result that these wells are often teeming with larvae. As these wells are large and wide, admitting a fair amount of light, anophelines are more readily found in them than in the disused wells built for drinking purposes which are narrow and dark.

Wheat Land.

It is the practice of agriculturalists to flood the land before the sowing of wheat. It generally dries up in a week, but on low lying badly levelled land water may remain long enough to permit mosquito breeding.

Disturbance of soil.

The turning up of new soil is frequently said to be the cause of malaria. As a general rule, fever is more rife than usual in a neighbourhood where there is some fresh land being cultivated, and in the course of a few years its frequency diminishes again. This fact was asserted by men of several years' residence in the Sudan, and moreover, natives of the country bore out their statement. After looking into the matter I have come to the conclusion that the turning up of the soil is not to blame, but the consequent irrigation of the soil. Naturally, in the first year of cultivation, the levels of the fields are not accurate, and consequently pools of water are left in the hollows. In the course of time these hills and hollows are levelled out in the subsequent cultivation, for it is only on evenly watered land that the agriculturalist can hope to get a nice even crop. (Fig. 12). The stagnant pools are thus done away with and mosquito breeding is reduced.

Entomological Conditions. The most important entomological factor for our consideration is the presence of mosquitoes, their variety, habits, and frequency.

Fig.12. - Levelling land.

Fig.13. - Low Nile showing
projecting stones and rocks
where Simulidae breed.

Blood Sucking Insects.

Before enlarging on this point it may be well to mention a few other blood-sucking insects in the Sudan:-

Owl midges belong to the Family Psychodidae (genus Phlebotomus). These minute flies are the cause of endless irritation. They attack the feet and ankles especially, and make their way under bed sheets with great tenacity of purpose. They are not easily seen except with a good light and when they are swollen with blood.

Sand-flies (Family Simulidae) are small hump-backed flies occurring in myriads at a certain time of the year, i, e, during low Nile. The larvae develop in shallow running water, clinging to rocks or stones. (Fig. 18). We were visited by Simulium griseicollis; and the Simulium damnosum occurs in great numbers in Dongola where there are many cataracts and exposed rocks in the river. I have had it suggested to me that these flies may carry malaria. Certainly malaria was very rife among natives during the six weeks that these flies visited us, but this could be accounted for by the cold nights and the consequent lowered resistance of the natives, and by the fact that mosquitoes were more numerous at this time of the year. Further, these flies occurred in myriads along the river banks and for several miles out into the desert. The air seemed full of them at dawn and towards sunset. They certainly could not depend on blood sucking for their existence, and out of the countless millions present it would be rare to be bitten by one which had previously had a feast of blood from another person. Their blood-sucking capabilities did not appear great. They were mostly annoying by the irritating way in which they persisted in getting into one's ears, nose, and eyes, and in creeping over one's neck and face. Authorities state that the malaria parasite does not develop in either the Simulidae or in the Phlebotomus.

The Families Chironomidae (midges), Tabanidae (gad flies), Hippoboscidae (spider flies), and Oestridae (bot flies) are all represented in the Sudan. Among the Muscinae found in the Southern Sudan is the Auchmeromyia luteola, the larva of which is the blood-sucking floor maggot of the Congo. Stomoxys and Glossina (tsetse fly) are also found. It is of interest to note that both Glossina morsitans (carrying Trypanosoma brucei) and Glossina palpalis (carrying T. gambiense) have been found in the Southern Sudan.

Mosquitoes. Mosquitoes belong to the order Diptera or true flies, and differ from all other flies in the possession of scales on the wings and body. In common with the other Diptera they possess two membranous wings, have mouth parts adapted for sucking, and undergo complete metamorphosis i, e, egg, larva, pupa, and imago. All mosquitoes except Mochlonyx and Corethra possess a long piercing proboscis, and this is a characteristic of the Family Culicidae.

The Culicidae are again subdivided into several sub-families, the division being based mainly on the relative lengths of the palps to the proboscis in the male and female. The venation of the wings and the character of the proboscis and antennae also serve as guides in this subdivision. The chief sub-families for our consideration are the Anophelinae and the Culicinae. (~~The Anophelinae and the Culicinae.~~) The Anophelinae have a straight proboscis, the palps both in the male and female are long, and the scutellum is simple and never trilobed. The Culicinae have a straight proboscis, but the palps in the female are short and insignificant, those of the male being long and plumose. (Fig. 14). As a general rule the wings of Anophelines are spotted due to areas of dark scales. This however cannot be considered a scientific basis to distinguish Anophelines from Culicines.. Some Anophelines have no wing spots, e, g. Anopheles bifurcatus, and some

Anophelines and Culicines.

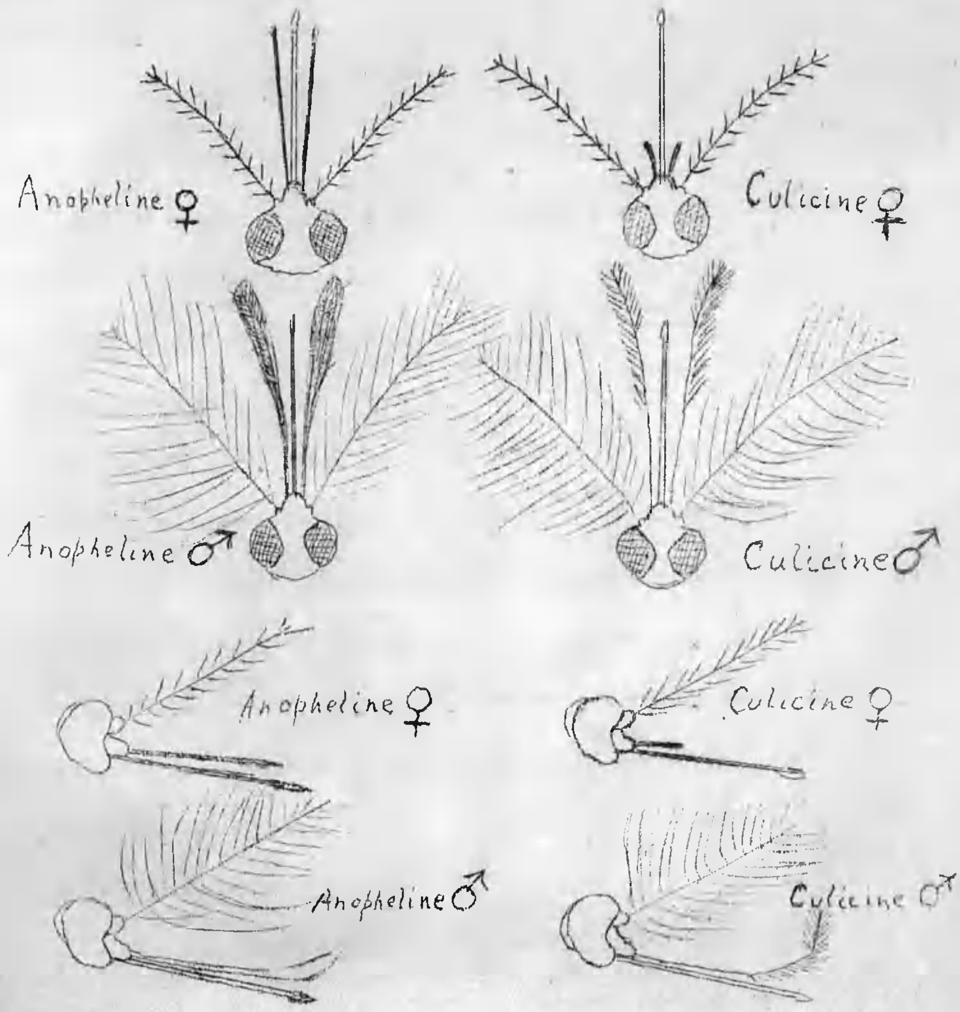

FIG. 14. MOSQUITOES' HEADS.— Dorsal and side views, comparing Anophelinae with Culicinae.

FIG. 15. RESTING POSTURE OF MOSQUITOES.

other Culicidae possess wing spots, e. g. Culex mimeticus and the genus Theobaldia. The attitude or resting posture of Anophelines differs from that of other mosquitoes. The proboscis forms a straight line with the rest of the body and points at an angle, in some cases almost a right angle, to the plane on which the insect is resting. The insect thus has the appearance of standing on its head. The angle formed between the proboscis and the surface on which the insect rests is held by some to vary according as the surface is horizontal or vertical, and some go so far as to give measurements of the angles according to the different species. I have frequently noted groups of Anophelines of the same species resting close together on the same object and have seen that the angle varied distinctly. I believe that the angle varies according as the balance of the body is affected by the amount of blood in the gut and the size of the ovaries. On the average, the angle formed by the insect resting on the under surface of a horizontal plane, such as the under surface of a shelf or table, most nearly approaches a right angle. Anophelines generally rest on the first two pairs of legs only, the third pair being held out straight behind in the air and frequently waving about. Myzomyia culicifacies is an Anopheline with a culex-like attitude. In other mosquitoes the abdomen is held parallel to the plane on which the insect is resting, or approaching towards this plane. The proboscis is directed towards the plane. There is thus an angle between the proboscis and the body of the insect giving the peculiar hunch-backed appearance. (Fig. 15.).

Resting Posture.

Humming Tone.

The humming tone varies in different mosquitoes. With a little experience one can tell whether a mosquito coming on to the attack is Culex fatigans or Pyretophorus costalis. The latter is an anopheline and has a much deeper tone than the Culex.

Ova. The ova of Anophelines are as a rule easily distinguishable from those of other mosquitoes. They are laid on the surface of the water in groups of 50 to 150, each egg floating seperately from its neighbours. They sometimes become arranged by capillary attraction, wind, and other physical causes into triangular and parallel figures. (Fig. 16.). The eggs are about one millimetre or less in length, are dark in colour, but have light coloured floats on the sides. They possess a fringe resembling the gunwale of a boat and are more or less boat-shaped. One end is thicker than the other and contains the head of the larva, and this end ruptures to allow the escape of the young larva. The ova of most Culicines are laid in a peculiar formation, the eggs being cemented together to form rafts. Each raft consists of 200 to 400 eggs. The eggs are elongated and are placed vertically side by side, their thick end pointing downwards. At this end they possess a bulbar appendage, "the micropilar apparatus", and when this is removed a short spine is sometimes left in its place. (Fig. 17). The eggs, which are about 1 millemetre in length, are white when laid but soon assume a dirty grey or brown colour. <u>Stegomyia fasciata</u>, although a Culicine, lays only about fifty eggs, each lying separately. They have a corrugated surface which retains air bubbles. They are rather larger than Anopheline ova. (Fig. 18). All mosquito eggs are in nature laid on the surface of water, at the edge of the water, or on a floating object such as a portion of leaf. Mosquitoes kept in captivity without water sometimes lay eggs on the sides of the glass vessel containing them. As a rule, ova do not withstand drying for long; two or three days in a dry state killing them. However, the ova of <u>Stegomyia fasciata</u> have been hatched after being kept dry for three months. The period necessary for the hatching out of larvae varies from twelve hours to two or three days according to the temperature, species, and other factors.

(a). (b)

Fig. 16.- Anopheline ova.- (a) Showing escape of Larva.
(b) Patterns assumed on water by eggs.

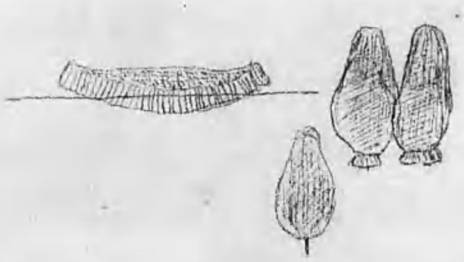

Fig. 17. - Culicine ova, with Egg-raft.

Fig. 18.- Stegomyia ova.

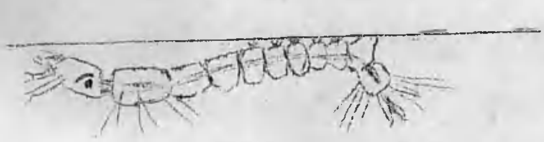

Fig. 19. - Anopheline Larva.

Fig. 20.- Culicine Larva, body tilted to show dorsum.

Fig. 21. Pupa.

Larvae. The larvae of Anophelines (Fig. 19.) lie horizontally immediately under the surface of the water. The abdominal segments possess on their outer dorsal surfaces palmate hairs which indent the surface of the water. When full grown they are about eight millimetres long. There is no syphon tube, the tracheae opening into a pit on the top of the eighth abdominal segment. The head is small compared with the size of the body. When about to change to the nymphal stage, the larva lets the head hang down after the fashion of Culicine larvae. When disturbed, Anopheline larvae move backwards just under the surface of the water in a series of jerking movements. If much disturbed, they dart down into the water. Culicine larvae lie at the surface of the water with their heads hanging downwards, the body thus forming an angle with the surface of the water. (Fig. 20). They possess a syphon tube on the eighth abdominal segment. The head is larger than that of Anopheline larvae, and there are no palmate hairs on the abdominal segments. Their mode of progression is wriggling, and they do not dart along the surface like Anophelines, but immediately wriggle downwards when disturbed. Stegomyia larvae hang head downwards almost vertically from the water surface. The head is smaller than that of other Culicine larvae and the thorax is not so sharply marked off from the abdomen. They have a lashing mode of progression and are frequently seen feeding at the bottom of the water. All mosquito larvae shed several moults in the course of their growth.

Food. They feed on the varied organic matter found in stagnant water, such as dead and living desmids, bacteria, and protozoa.

Cannibalism of larvae. I have noticed large larvae attack and devour small larvae even of the same species. They are frequently seen eating cast off moults of other larvae. It is well to be familiar with other aquatic larvae which might be mistaken for mosquito larvae, such as Dixidae, Corethra, Chironomidae, and Ephemeridae.

Pupae. The pupae of Culicidae are peculiar comma-shaped objects consisting of a large globular portion (head and thorax), and a tail tucked in underneath. Two syphon tubes are situated at the upper dorsal surface of the globular portion. (Fig. 21). The pupae are at first light brown in colour, but soon darken. They are much less active than larvae, and usually rest at the surface of the water, but when disturbed wriggle down into the water. When rising to the surface they do not exhibit this wriggling movement. When the mosquito is about to emerge, the tail straightens out. The generic points of pupae are not easily differentiated by the naked eye, but microscopically the syphon tubes can be seen to differ. My usual practice in making a diagnosis of the species of a pupa was to await the emergence of the imago. The mosquito emerges through a rupture on the dorsum of the globular part of the pupa case. It is most interesting to watch this process. One wonders how the insect contrives to extricate itself from the small pupa case. The long hind legs, which are wet and pliable and appear so helpless, are the last members to be withdrawn. One expects the helpless looking insect to fall off the pupa case into the water, but wings and legs soon dry and harden, and the full fledged mosquito takes flight. Pupae do not feed. The time taken for development from egg to imago varies considerably according to circumstances of temperature, light, and food. Culicine eggs frequently breed out imagines in ten days, but Anophelines take longer, and in my experience are more susceptible to artificial conditions and frequently die in captivity. Under unfavourable circumstances the process may take several weeks. Anophelines can be reared from eggs in fourteen days in artificial surroundings. I have found pupae of Pyretophorus costalis in a collection of water said to have been in existance for only seven days, and have hatched some of these pupae the following day. This gives a period at most of eight days from egg to imago. I cannot vouch for the accuracy of this statement, but it is quite possible that the process of development may be sometimes more rapid under natural than under artificial conditions.

Sudanese Mosquitoes. Dr. Balfour, Director of the Wellcome Research Laboratories in Khartum, has made a collection of Sudanese Culicidae, having had specimens sent to him from all parts of the country. He has from time to time sent specimens for identification and classification to Mr. Theobald, who has named several new species from among them. In the Third Report of the Laboratories, a list of twenty genera comprising forty-three species of Sudanese Culicidae is given by Mr. Theobald. Myzomyia funesta, Pyretophorus costalis, and Cellia pharoensis all occur and are known malaria-carriers but, as Dr. Balfour suggests, Anopheles wellcomei, Myzorhyncus paludis, Myzomyia nili, Cellia squamosa and others require to be carefully experimented with before they can be definitely described as not implicated in the traffic.

The three species of mosquitoes prevalent in our Plantation, namely, Pyretophorus costalis, Culex fatigans, and Stegomyia fasciata vel calopus, may be taken as types representing the three divisions of Culicidae of most scientific interest. Pyretophorus costalis is a good example of a malaria-carrying Anopheline. Culex fatigans is a Culicine, and is active in the conveyance of protozoma of birds, and of certain small filariae (Filaria nocturna, the larval form of F. bancrofti). It is also credited with the conveyance of dengue by some observers (Graham).

Yellow Fever. Stegomyia fasciata is also a Culicine. The main point of interest in this mosquito is the fact that it is the known carrier of yellow fever. The danger of its presence is not far to seek. Two elements necessary for the development of yellow fever are present, namely, man and the Stegomyia fasciata. It only wants the presence of the third element, namely, the organism (whatever it is) of yellow fever, to have this fell disease rife in the country. This mosquito is found at the sea ports of Egypt and the Sudan ready to spread any yellow fever brought to the country. The formation of a direct line of steamers between yellow fever districts and Egypt would require expert supervision and special quarantine laws to keep the disease out of the country.

Habits of Mosquitoes. In the study of the mosquito

Food. problem one must consider carefully the habits of mosquitoes. The males feed on vegetable juices, but the females in addition suck the blood of human beings, birds, and many mammalia. Copulation is said to take place during flight.

Hibernation. In certain countries mosquitoes hibernate. During this period impregnated adult females may be found in a semi-dormant condition in dark corners. Stegomyia fasciata propably is propagated after winter from eggs laid at the end of the previous autumn, as the eggs can resist drying for months. Other mosquitoes may hibernate in the larval form, as some larvae have been found in water covered with ice and have afterwards developed. (Le Dantec). In Berber Province there is no hibernation. In fact, the mosquitoes are most numerous in the cold weather. On the other hand

Aestivation. "aestivation" may be said to exist to a certain extent. In the hot dry weather, before the rainy season, mosquitoes diminish in numbers. This might be explained by the fact that most of the breeding places have dried up naturally, and that irrigation is at a minimum, the wheat and cotton crops being completed. Nevertheless, the mosquitoes found in dark corners in the hottest part of the year are more difficult to disturb, seem more indolent, and certainly do not cause the annoyance that they do in winter time. Even when plenty of water is at hand they do not lay eggs to any great extent.

Breeding places of Anophelines. As a rule Anophelines breed in shallow pools of water exposed to light. Their larvae are mostly found in muddy pools left by the drying up of "Khors", or left by the falling Nile on its banks, and in pools among crops due to irrigation of imperfectly levelled land. Still, I have found them in "zeers", in wells, and at the edges of canals where the current of water was checked by grasses or branches of trees. It was only after the "aestivation period" that they were found in zeers. The mosquitoes, still drowsy after their long rest, probably laid their eggs on the nearest water instead of going farther afield as is their wont. Dr. Balfour reports the finding of P. costalis larvae in a well seventy feet deep at Omdurman. This is rather unusual as Anophelines generally breed where there is plenty of light, and there could be little light at that depth.

Breeding places of Culicines. The larvae of Culex fatigans are found in almost any stagnant water but they show a preference for dark places, such as wells, zeers, bath cisterns, and shaded pools. They are numerous in pools among the cotton, the cotton plants forming an efficient shade. They are also found in leaking boats, the earthenware vessels of "Sakias" not in use, and in household utensils containing water. Stegomyia fasciata resembles Culex fatigans in its breeding habits, but is credited with a special affinity for the bilge water of river steamers. It can be easily understood that this breeding of mosquitoes in boats is a method of transportation which is often troublesome. Thus at Khartum a system of boat inspection has to be enforced in order to prevent the reinfection of Khartum with mosquitoes from boats.

Feeding Time. P. Costalis and C. fatigans generally bite at dusk and during the night, but I have occasionally watched P. costalis enjoy a meal in the broad daylight. As a rule they avoid light, and consequently, when dining, one's ankles suffer most from bites. By placing a light underneath the dining table we sometimes escaped the attentions of the pests. They frequently bite through the openwork of cane-bottomed chairs. A newspaper placed on the chair is an efficient preventive. Stegomyia fasciata seems to feed at any time, day or night, and if numerous, these mosquitoes are often troublesome on this account.

Resting Places.

In the daytime, mosquitoes are generally found in dark corners of houses, offices, huts, outhouses and stables. They are often seen resting on the under surfaces of tables, shelves, and on dark clothing and objects. Some show a tendency to rest on certain substances, such as leather. Once I chloroformed 27 of the species P. costalis in a leather boot.

Flight.

There is some difference of opinion as to the distance that mosquitoes will voluntarily travel. Most authorities admit that Anophelines will fly half a mile between the feeding ground and the breeding ground if there is no breeding place nearer at hand. Others mention quarter of a mile as the extent of unassisted flight. In most instances there are breeding places within easy reach of the huts and stables which serve as feeding grounds. I visited a Plantation up the river Atbara, close to the scene of Kitchener's crushing defeat of Mahmoud in his famous "zareba", and there found that the Manager had taken advice as to a dry-belt and lived on the desert fully half a mile from the river. There were no trees worthy of the name, and no cultivation within a quarter of a mile of his house. Nevertheless, he and his retinue were constantly suffering from repeated attacks of fever. I looked for a well as a breeding place for mosquitoes but found none. The water was brought daily from the river in skins. One must conclude that the mosquitoes bred either in the irrigated cultivation or on the river banks, and must at least have travelled a quarter of a mile to the house. The infection of pools at our pumping station (mentioned under

Tree belt.) support the view that P. costalis only travels a distance of half a mile when there is a favourable wind. Strong winds may carry mosquitoes long distances, but they naturally seek shelter and never take flight during high winds if they can avoid it. Their flight is low as a rule, a fact which we made use of in our sleeping arrangements. By sleeping on the roof, about forty feet from the ground, we were little troubled by mosquitoes, whereas when sleeping at a lower level or in the garden we were constantly besieged by them.

MOSQUITO PROPHYLAXIS.

Natural Enemies. Like all other forms of life, mosquitoes have their natural enemies. By encouraging the multiplication of these enemies one naturally expects to diminish the number of mosquitoes in a district. Certain small fish and certain water beetles and their larvae frequently devour mosquito eggs and larvae. The larvae of dragon flies are believed by many to account for large numbers of mosquito larvae, but this destruction is exaggerated, as the dragon fly larvae generally feed at the bottom of the water while mosquito larvae live mostly near the surface. Some people state that frogs and tadpoles destroy mosquito larvae and ought to be encouraged in malarial districts. Certainly in the Sudan my experience showed them to be of no value in this respect. I have regularly examined a small water collection containing numerous frogs and tadpoles and found it more highly and more regularly infected with larvae of C. fatigans and P. costalis than any other pool I can recollect. At our Plantation, numerous mosquito larvae were destroyed by birds, notably by the various species of water wagtail. Many shallow pools were kept practically free from larvae by these birds. In India, mosquito larvae are said to be

Enemies of Larvae.

frequently infested by Gregarines, but it is not known if these Sporozoa cause the death of the larvae. As mentioned before, there is a degree of cannibalism among mosquito larvae, and this may be one of nature's methods of controlling the multiplication of mosquitoes.

Enemies of adult Mosquitoes.

Adult mosquitoes are devoured by bats, dragon flies, and certain small night birds. Tiny red parasitic mites have been found infecting adult mosquitoes in the Sudan, and may shorten life. Agamomermis culicis (a round worm) has been found in the abdominal cavity of Culex sollicitans. Felt mentions that mosquitoes may be infested with the fungus diseases Entomophthora sphaerosperma, Empusa culicis, and possibly Empusa papilata. Acarines, crithidia, sporozoa, and minute trematodes have also infested mosquitoes. The practical application of our knowledge of the natural enemies of mosquitoes and their larvae has up to the present been decidedly discouraging. Attempts have been made to spread some of the fungus diseases among mosquitoes but without success. Still the subject should not be given up in hopelessness. I had the opportunity of witnessing an analogous case when dealing with locusts.

A disease among Locusts.

During a visit of swarms of locusts (Schistocerca peregrina) it was noticed that large numbers sickened and died. In the body cavities of these locusts maggots were found. I hatched some of these larvae in earth, and found that they gave rise to a species of Tachina fly. Our Manager, Mr. Nevile, had found the same condition of affairs during a visit of locusts in 1905. The number of deaths among locusts from the Tachina fly was certainly considerable, and made one think that in dry countries, which are favourable to the breeding of Tachina flies, they might be utilised as a means of limiting the number of locusts. On the same lines, perhaps, one of the numerous parasites which infest mosquitoes may be turned to good account in the future.

Practical use of Enemies. It is well to encourage and leave unmolested all varieties of water birds which frequent the shallow pools. It is also good practice to encourage the breeding of small fish in the irrigation system. Our pumps brought many fish from the river into our canals, and the small varieties reached the smallest canals and no doubt devoured many mosquito larvae. Numerous kingfishers hovered over the canals and fed on these fish. To prevent this destruction of fish, it was suggested that we should shoot the birds, but as a kingfisher poised in the air can hardly be called a sporting shot, I fear the suggestion was not carried out.

Destruction of Mosquito Larvae. The rational method of exterminating, or reducing the numbers of, mosquitoes is to attack them in their larval stage, or what is better, to make the conditions such that the development from egg to imago cannot take place. This latter largely resolves itself into an engineering problem. Eggs only hatch in water, and larvae only reach maturity in water which is stagnant or only slowly moving. We must therefore aim at

Prevention of water Collections. the prevention of stagnant pools, disused wells, collections of water in house utensils seldom used, and in old discarded preserved meat tins and other vessels. Irrigation systems in gardens and farms and wells in daily use must receive careful attention.

Water Supply. In towns in the Tropics a powerful weapon in the fight against mosquitoes is the installation of an efficient water supply system with mains, service pipes, and house pipes, together with an accompanying system of drainage for the waste and storm waters. We can then do away with wells and the old methods of storing water in household utensils, open bath cisterns, and fire buckets. Waste waters and surface collections of storm water are rapidly dealt with, and gardens can be watered by hose pipes instead of by faulty irrigation systems. Where such a system is impossible or its cost is prohibitive many devices may be utilised to forward mosquito prophylaxis.

A system of legislation in Towns.

(1). All wells should be under direct control of the Sanitary Authority, and new wells allowed only with its sanction. Owners of wells should be compelled to provide suitable covers for them. Pumps at the surface should be advised, as by their use the entrance of mosquitoes and deposition of eggs is prevented. Wells from which water is drawn in buckets may easily become infected. The natives carelessly leave the covers off, or the mouths not efficiently closed, the climate warps the wood, or the rain washes away the earth from the mouth of the well, and the female mosquito heavy with ova and anxious to find water on which to deposit them soon finds the open chinks.

(2). All wells should be inspected regularly by competent Inspectors. Any repairs to the cover should be seen to, and if the water contains mosquito larvae a suitable larvicide should be applied.

(3). All disused and unnecessary wells should be filled in.

(4). Householders should notify the Sanitary Authority when they intend to shut up their premises for any length of time. Before the premises are locked up an Inspector can visit them and see that no water is left in utensils or storage cisterns, and that the well in the yard is efficiently covered or treated with larvicide.

(5). All surface collections of water in or near the town should be drained, or the hollows should be filled up, and where this is impossible they should be regularly inspected and treated with larvicide if necessary.

(6). Means should be taken to prevent the carrying of mosquitoes or their larvae to the town by steamers, native boats, or trains. Regulations enforcing the treatment with larvicides of bilge water and other water collections on river steamers before approaching the town are necessary. Native boats, if leaking, can be treated immediately on arrival. Larvae are not carried by trains, the water tanks being too often emptied to allow of their development. Adult mosquitoes may be carried in railway carriages and can only be destroyed there by fumigation.

(7). Where possible, a dry belt a mile wide free from cultivation and irrigation but with a tree belt on its outer margin should be left around the town. Mosquitoes then cannot breed near enough the town to fly there voluntarily, and the tree belt acts as a screen to catch mosquitoes which are being blown by wind towards the town.

At Khartum a system in many respects similar to the above has been instituted by Dr. Balfour with excellent results, and at very trifling cost. As in all other undertakings in the Sudan, efficiency has only been reached at the cost of much labour and disappointment to the instigator. To expect thoroughness in anything from the Sudanese people is to court disappointment. Promises are always given with the qualifying clause "in-sha-alla" (God willing). One generally finds that they have been pleased to consider that God was not willing in the matter.

Difficulties in Rural Districts.

In agricultural districts such as that at which I was stationed, and where irrigation is of prime importance, the difficulties of mosquito prophylaxis are greatly multiplied. The area to be treated at our Plantation was large, the concession for cultivation being over 10,000 acres in extent, and the neighbouring native lands and villages also required attention. There was no Local Sanitary Authority, and although in villages on our own land we exercised a certain amount of self constituted authority in matters sanitary, still the numerous villages and groups of houses bordering on the Plantation, and in some cases within a few hundred yards of our living quarters, were entirely outwith our jurisdiction. The principal village was within easy reach of the main canal where natives could obtain ample water, and the wells, which were contaminated with sewage as well as infected with mosquito larvae, were filled in. Houses were visited regularly and water storage vessels were inspected and discouraged. At our own quarters a well was used for washing purposes, but it was in regular daily use and sufficiently disturbed to prevent the development of mosquito larvae. It was never found infected. Drinking water was brought daily from the Nile and stored in "zeers", which were emptied and cleaned at least once a week. Large iron cisterns were placed at intervals round the house and contained water in readiness in case of fire. They were not supplied with covers and were so frequently infected with larvae that their use was advised against till suitable covers were procured. It is of the ~~(most)~~ utmost importance that all European quarters should be placed at a considerable distance from native quarters, and this is a consideration which had not been carried out sufficiently at our Plantation. Native huts harbour infected Anophelines, and it is folly to build European quarters within the range of their nightly explorations. It was difficult to get disused wells and sakis pits on neighbouring land filled in, but, where these were near enough our quarters to be a source of annoyance and danger to us, the Acting Governor of the Province kindly assisted us when his co-operation was requested. At the expense of a little supervision, the foregoing methods of mosquito prophylaxis were efficiently dealt with. The main sources of danger were much more difficult to tackle. I refer to the irrigation system, the pools left in Khors, and there on the river bank. Rain pools also required attention, but, as mentioned before, they gave me little trouble.

Isolation of European Quarters from Native Quarters.

Irrigation System.

A glance at the accompanying sketch of the Plantation (Fig. 22) will give one a better idea of the magnitude

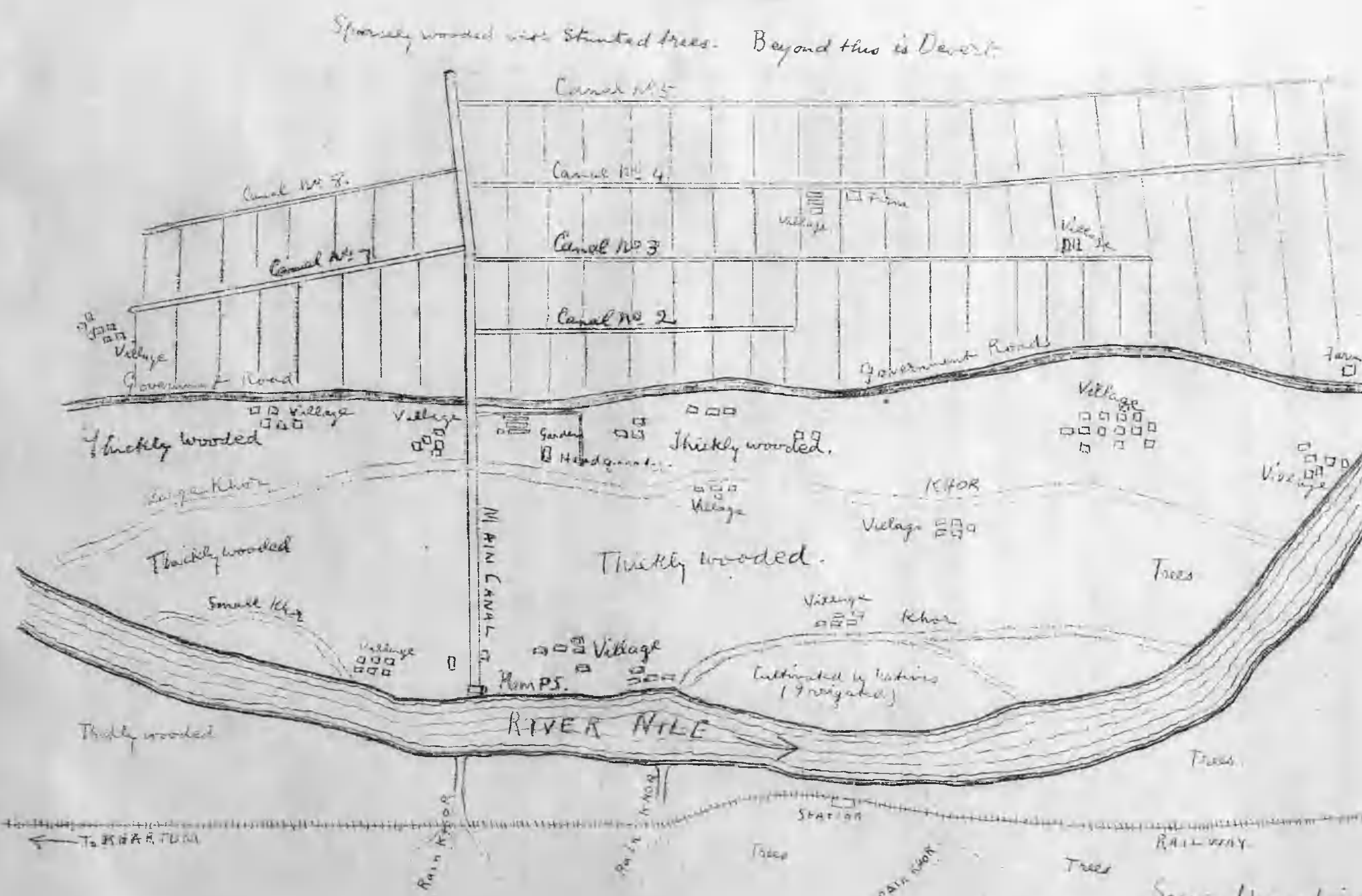

FIG. 22. ROUGH SKETCH PLAN OF PLANTATION (with Irrigation System.)

of the work necessary. The main canal was fed with water at the Nile bank by large centrifugal pumps. (Fig.23). It was about six kilometres in length, and subsidiary canals, 8 in number, were supplied by it. The subsidiary canals supplied smaller canals or gadwals running at right angles to them at intervals. Each gadwal supplied water for a plot of land about seventy acres in extent. The gadwals in turn gave rise to small ditches running direct on to the cultivated land. The main canal was never found to contain mosquito larvae. The current was too rapid. As we passed from this large channel towards the smaller channels the rate of infection varied roughly in inverse proportion to their size. The subsidiary canals were seldom found to contain mosquito larvae, but at a time of year when the crops were well advanced and required water only at long intervals, they were found infected at their extremities, or where grasses, branches, or logs of wood were able to dam back the very slow current. The gadwals were more frequently infected especially at their extremities, and the ultimate small ditches and furrows rising from them, if low lying and containing water for a sufficient length of time, were still more frequently infected. To successfully deal with such a system from the point of view of mosquito prophylaxis one must collaborate with the Civil Engineer when he is laying out the irrigation system. The system at our Plantation was completed before my arrival, and unfortunately the mosquito problem had not received much consideration. Several defects in the system became evident, the rectifying of which would have proved expensive, but which if seen to during the making of the system would have caused little additional expense if any. For instance, many of the canals were continued farther than was necessary, i, e, past the exit of the last necessary gadwal. In this way blind ends were formed which served no useful purpose, and as water there remained stagnant and grasses

Infection of Channels.

Defects in the System.

(a)

(b)

(c)

Fig.23. - Irrigation System. (a) Pumping station and main canal.
(b) Subsidiary canal - sheep washing.
(c) Gadwal - The result of native driving.

and floating objects collected, mosquito breeding often proceeded. By taking the last necessary gadwal from the extremity of the canal this dead end is done away with, and every time the gadwal is used the water at the extremity of the canal is the first to be put in motion, and any larvae in process of development will be injured by the sudden rush of water into the gadwal. The same remark stand good as regards blind ends in the gadwals themselves. Where these existed, they were almost invariably infected. Then again the levels of canals, gadwals, and land supplied by them were not always sufficiently accurate. Gadwals sometimes could not be drained dry by the land which they supplied as the beds of the gadwals were sometimes lower instead of higher than the land. Some plots of land were badly levelled, allowing water to stand several inches deep in the low lying parts when the higher parts of the plot were dry. These deficiencies naturally led to a considerable increase in mosquito breeding. Without doubt, efficient levelling is the most important factor in an irrigation system from the point of view of mosquito prophylaxis. The levels of canals, gadwals, and plots of land irrigated by them must be set to a nicety. Thus, towards the end of irrigation of a plot of land, it should be possible to run the gadwal supplying this land absolutely dry. When irrigation of a crop is required only once in three or four weeks this is important. If the crop is watered once a week it is unnecessary to run the gadwal dry, as mosquito larvae in its water have not reached maturity in a week, and are carried to the land at the next watering and there dry up if not actually injured in the transit. Sluice gates generally leak a little, and it is well to leave a hollow at the head of the gadwal to collect this leakage in a limited area. This collection can be easily and cheaply treated with larvicide. If no hollow if left little shallow pools collect along the bed of the gadwal and thus a bigger area requires treatment.

Fallow Land. It may happen that the land supplied by the ultimate or distal portion of a canal is left fallow for several months. If no provision is made for this contingency, the whole canal must contain water in order that the land supplied by its proximal or first part may be irrigated. The water in the distal portion of the canal, not being drawn off to the land, is left more or less stagnant and there is thus danger of mosquito breeding. There is also a certain waste of water by evaporation and leakage. It is therefore a good plan to have at intervals across the canal suitable gates to shut off water from the distal portion. In this way the distal section of the canal can be run dry, provided the level of its bed is high enough, at the last watering of the land it supplies, and remain dry while the land is lying fallow. In the case of land supplied by the proximal section of a canal lying fallow, the same objections do not hold good. The current of water, passing along this section to reach the distal sections from which water is drawn, is usually sufficient to interfere with mosquito breeding.

Regular Watering. By arranging the watering of the different plots of land in regular rotation, and by running gadwals dry when the land is only watered at intervals exceeding one week, one may limit the amount of stagnant water on a plantation to a great extent. I regret that this was not carried out properly at our Plantation. This was not the fault of the system, but of the bungling careless methods of the Egyptian overseers and native tenants.

Government Assistance. Perhaps Government could do something towards the lessening of malaria by requiring all plantations to submit plans of their irrigation systems before making them. A Government Civil Engineer with a sound knowledge of mosquito breeding, or in conjunction with a Medical man possessing that knowledge, could see that the systems were rational, and that accurate levelling of canals and land was enforced. After completion, plantations could be under the supervision of a Government Inspector who could report on the care with which irrigation was carried out and breeding pools prevented. Grants of money might be allowed by Government to plantations if the Inspectors reports were satisfactory.

Mosquito Brigade. An intelligent native at a salary of £2. per month can be trained in the recognition of mosquito larvae, their habits and haunts, and the best means of preventing them. With the assistance of two labourers, each at a salary of £1. per month, he should be able to keep 2000 acres of cultivated land free from mosquito breeding places provided the plantation has been "ab initio" accurately planned and levelled, and is irrigated on a system of regular rotation and with care. His work will mainly consist of the levelling up of pools left in the beds of gadwals and canals, and the keeping of the various channels free from branches of trees, grasses, or anything likely to interfere with the current. Stagnant pools which cannot be drained can be treated with larvicide. Thus for an expenditure of £50. on labour and about £5. on larvicides a fairly large farm can be kept practically free from malaria. Where irrigation systems are faulty the expense will be much greater, and where many Khor pools are near further allowance must be made.

Drainage System. The proposal to form a subsidiary system of drainage canals to drain off gadwals and low lying land was mooted at our Plantation, but was dropped when the expense necessary was considered. In a country so flat, drainage is difficult, and in any case there is no need for such a system if the levels are so arranged that the land can drain gadwals dry, and gadwals can drain canals dry, the land being sufficiently level to prevent the formation of pools.

Treatment of natural water collections. The treatment of "Khor" pools and other natural collections of water must be dealt with by the mosquito brigade, if these pools are near enough to be a source of danger. Occasionally the mouth of a Khor might be filled up and the water kept out at high Nile. This would entail much expense and would require yearly repair, and might interfere with the water supply to some adjoining native lands. Accordingly it is only occasionally that these natural collections can be treated in a permanent fashion. The mosquito brigade must therefore give attention to them annually, and by ditching, levelling, and the free use of larvicides may prevent mosquito breeding from proceeding in the immediate neighbourhood.

It is questionable if one has a right to expect a commercial concern to expend money on mosquito prophylaxis, especially when one considers that the area occupied by plantations is infinitesimal as compared with the area over which malaria is prevalent in the Sudan. Government grants would be useful, but is it advisable to spend money on a project which only attacks the fringe of the malarial problem in the country.?

Larvicides. In dealing with water collections which cannot be removed but which harbour mosquito larvae, we must use larvicides. These may be divided into two main classes:-

(1). Those that act by forming a film on the surface of the water so that larvae and pupae cannot penetrate it to breathe,

(2). Those that act by forming a mixture with water which is poisonous to the larvae or destroys the food of the larvae,

There are arguments for and against each class. Various oils belong to the first class of larvicides and form a film which kills both larvae and pupae. Their syphon tubes become blocked by oil and so respiration cannot take place. It is easy to gauge the amount of oil necessary by noting the extent and quality of the film formed. The amount required depends upon the surface area of the water and not upon the amount of water. Thus deep wells can be cheaply treated with a small amount of oil, whereas the amount of soluble or miscible larvicide required would be proportional to the mass of water. A gallon of kerosene is said to form an effective film over an area of 3000 square yards within two days and to be free from danger of fire (Jackson). With a little experience one can gauge the amount necessary for a given area and the resulting film can be judged as effective or not by a little observation. Where large areas of water require treatment a spray is of use, but in the small collections of water, where mosquito breeding is most liable to occur, the oil may be poured on the surface at different places, and the water can be agitated with a branch or stick and the film efficiently spread. Where grass grows at the shallow margins of pools it may interfere with the spreading of the film. Extra care is therefore required. The main objection to the use of the first class of larvicide is the rapidity with which the film sometimes disappears. Wind or current may carry the film along the water, and in a few days all the film may be found at one end of the pool while the other end is free from it. Statements to the effect that water collections need only be treated with oil once a fortnight are only relatively correct. A large pool of water exposed to wind may have the film removed from one end in one day. Mosquitoes may under favourable conditions develop from egg to imago in eight days. It will thus be seen that under certain conditions pools may require treatment with oil every eight or ten days. On the other hand stagnant pools, well protected from wind and other surface disturbance, may retain an efficient oil film for several weeks.

The oil employed in any district is generally that which can be most easily and cheaply obtained. Any of the mineral oils used for lighting purposes are effective and we used cheap petroleum at our Plantation. J. B. Smith, of New Jersey, advocates the use of Phinotas Oil which, besides forming a surface film, is deadly to larvae by acting as a direct poison, but it is very destructive to fish and aquatic life in general.

The advantage of the second class of larvicides is that so long as the poison remains and is not unduly diluted larval growth is inhibited. Against its use is the fact that pupae are not destroyed as they do not feed in this stage, and also the fact that fish may be destroyed. Most of the ordinary disinfectants are too expensive for use. Chloride of lime, finely powdered and scattered on the surface, is good temporarily, but soon sinks to the bottom and becomes inert. Fourteen grains to the quart of water are said to be effective. Dr. Balfour experimented with Derris root emulsion at Khartum and proved it an efficient larvicide. As the root does not grow in the Sudan, the expense of obtaining it contra-indicates its use there. Various coal tar preparations have been used effectively. Empty tar barrels may be utilised by placing them in slowly moving water. A gradual admixture of small quantities of tar with water takes place and a continuous film is formed on the surface and is slowly carried away by the current. There are some automatic devices in use whereby a certain amount of oil is liberated at regular intervals in canals with a very slow current. Larvicides forming a film will as a rule be found more convenient and economical than those of the second class.

Fumigation. <u>Destruction of Adult Mosquitoes.</u> Methods of killing adult mosquitoes are sometimes employed. They are of advantage in dealing with mosquitoes brought by trains, but as a means of treating the mosquito problem are hopeless, without at the same time having breeding places and larvae dealt with. Windows and doors may be closed and sulphur burned. For each 1000 cubic feet of air space 2 lbs. of sulphur are required. Campho-phenique, which consists of equal parts of camphor and carbolic acid, heated by an alcohol lamp is cheap and efficient. Four ounces per 1000 cubic feet of air space are necessary. I found that offices and rooms could be kept fairly well clear of mosquitoes by sprinkling paraffin oil about the walls and floors. Where there is much woodwork the danger of fire may contra-indicate this treatment.

Prevention of Mosquito bites.

Medicaments are often applied to the skin to keep mosquitoes at bay. Of ~~course~~ these oil of citronella seems to be the favourite, but I have no experience of its use. It is said to have little effect on African mosquitoes. Carbolic lotion is useful while its odour lasts, and may enable one to get to sleep before mosquitoes will venture and attack. Its application is also soothing to bites already received. Paraffin oil rubbed on the skin, although not an elegant preparation, is extremely effective. I was indebted to its use for many nights free from the attentions of mosquitoes and owl midges.

Mosquito-proof houses and nets.

Mosquito houses in the Tropics are excellent in theory but useless in practice. The netting is easily damaged, doors and windows are left open by careless servants, and in any case the temperature in the rooms is often too high for comfort and it is preferable to dine and sleep outside.

A mosquito net over one's bed is of service but cannot be used at all times with comfort. In very hot weather one dispenses with the net in order to get more air and so is exposed to mosquitoes. At other times a sudden "haboub" will make short work of the net if one sleeps in the open. Mosquitoes are not in evidence during the haboub, but the wind soon falls and the air becomes perfectly still again. The mosquitoes come out from their shelters and find one an easy prey after the mosquito net has been torn by the wind.

QUININE AS A PROPHYLACTIC IN MALARIA.

Methods of Administration.

Authorities are unanimous in admitting the value of quinine as a prophylactic in malaria. There are, however, many different opinions as to the best salt of quinine to use and the best method of administration. Ziemann advocates the administration of quinine or of euquinine in doses of ½ to 1 gramme every four days. Those who cannot tolerate ½ gramme of euquinine are advised not to go to the Tropics. As an aid to memory he recommends that the quinine should be taken on the 1st., 4th., 8th., and so on, in fact on all dates divisible by 4 up to the 28th. of the month, and should then be begun again on the 1st of the following month.

Rogers recommends 10 to 15 grains for an adult, taken twice a week, either on two successive days or on every third andfourth day alternatively.

Darker of Southern Nigeria recommends the intracellular injection of 15 grains of a dense solution of quinine hydrochloride (neutral salt) in the case of children. He claims that the quinine solidifies in the cellular tissue under the skin and is absorbed slowly in about two months.

Celli in Italy advocates as a prophylactic the daily administration of quinine bisulphate, hydrochlorate, or bi-hydrochlorate in doses of 40 centigrams for adults and youths, and 20 centigrams for children. He claims that quinine is thus much better tolerated than one would expect, that it acts as a tonic to the digestive apparatus and muscles, and as an aid to nutrition. It can be stopped when necessary without causing disturbance, and does not interfere with the efficacy of large doses when these are necessary.

Many authorities are in favour of subcutaneous or intramuscular injections. The bi-hydrochloride is most generally employed through the acid hydrobromide, hydrochloro-carbamide, euquinine, and the sulphate dissolved with tartaric acid are all used. Most of the advocates of injection claim greater certainty and rapidity of absorption, but all seem to note the fact of a lessened tendency to cinchonism. This probably points to a lessened and slower absorption, but this very fact may be advantageous when a prophylactic action is desired, the effect extending over a more lengthened period. If rapid absorption is desired, as in malignant malaria with cerebral symptoms, the most rational procedure is intra-venous injection.

Perhaps I may be considered behind the times as I confined my attention to the giving of quinine by mouth as a prophylactic, and was content to use the somewhat out-of-fashion salts, the sulphate and the bi-sulphate of quinine. Nevertheless the results seemed to justify the procedure. The sulphate was mostly used, given either as a powder or dissolved in an acid solution, but there seemed to be no advantage of the one over the other. The bi-sulphate was given in tabloids or in powder form. On the assumption that an interval of about a fortnight elapses between the inoculation of sporozoites by an Anopheline and the first febrile attack, I gave a large dose of quinine at intervals of seven days in the hope of killing any developing parasites. From 15 to 20 grains were given, usually every Saturday night. Of course new comers were given small daily doses at first, and the dose was gradually increased and the interval between doses gradually lengthened till 15 or 20 grains could be taken without inconvenience. This method acted well, but sometimes after a 20 grain dose an effect on one's nervous system was noticed as evidenced by inaccurate shooting next morning, and slight singing in the ears was occasionally produced if one required to undergo much physical exertion or remain long exposed to the hot sun. I therefore modified the dose to 10 or 15 grains taken on two successive nights each week. Saturday and Sunday nights were recognised as "quinine" nights. By this method, although a smaller dose was taken at a time, the chance of having quinine circulating in the blood during the extracorpuscular stage of the parasites was increased, and so a smaller amount of quinine was effectual in killing them. This system is identical with Rogers' system although at the time I did not know of Rogers. It certainly gave excellent results and cinchonism did not occur. After a few sharp attacks of malaria Europeans were generally willing to take quinine in the above method, and their improved health and freedom from malaria encouraged them to continue it. Natives were difficult to deal with. When in good health they could not understand the necessity of taking medicine, but the more intelligent natives got into the habit of taking doses at intervals of four or five days and benefited accordingly.

IMMUNITY.

Under the heading of malaria prophylaxis let me briefly mention a natural prophylaxis which exists. I refer to immunity. There is no doubt that the natives of a malarial district suffer less from malaria than people who come from other districts. I have no doubt that a certain immunity is produced by repeated attacks, and in all probability this immunity is transmitted in a slight degree to the offspring, for although parasites may not pass to the placenta the toxins will. Malaria is rife among infants and children, and many die from it. Still, in the majority of instances, these little ones run about and play like ordinary children in the intermissions of the fever. They develop a large spleen, are usually thin and poorly nourished, but appear quite healthy and happy when no fever is present. In this way an immunity is produced which stands them in good stead in later life.

Many villages in Berber province are practically free from malaria, especially those on the right or high bank of the Nile where khors and resulting stagnant pools are scarce. We had many workmen at our Plantation of the same race as the natives of our district but from non-malarial districts. The attacks of malaria acquired by them, after living a few weeks with us, were always more severe and lasting than those acquired by our villagers. I had an excellent opportunity of noting the gradual immunising process of these incomers. New arrivals had frequent recurring malarial attacks, whereas men of three or four years residence were, like the natives of the place, only very occasionally affected. The natives themselves recognised this production of immunity. I have heard them say that the air of the place was very bad for strangers and gave them fever, but that in course of a few years they got accustomed to it and kept healthy. I remember a groom whose first year of residence at our village was a long series of recurring malarial attacks. He intended returning to his own village but remained when his younger brother joined him. The younger brother duly acquired his malarial infection and had a hard time of it. For six attacks of the younger brother, the elder one had a single attack. They were of the same flesh and blood, lived in the same room and under similar conditions, and were going through the same process of immunisation the elder brother a year ahead of the younger. I can recollect numerous cases with a similar result. Some suggest that the insusceptibility to malaria of natives of malarial districts is produced by a weeding out of the weaklings and "the survival of the fittest". This may to a certain extent assist in the production of the immunity enjoyed by such natives, but it cannot explain the immunity acquired by strangers after a few years' residence in a malarial district.

Racial Susceptibility.

That there is a racial susceptibility to malaria there is good cause for belief. At our Plantation were Britons, Greeks, and other Europeans, Syrians, Egyptians, and many different tribes of Arabs and Sudanese. Of all these the Egyptian fellahin suffered most severely from malaria. Gangs of them came to us on a six month's contract. Physically finer specimens of men could scarcely be found. The less said about their mental and moral state the better. They might be termed the "fit survivors", for their upbringing has been amidst the most insanitary surroundings and their hardships have been many. They arrived sound in wind and limb and well nourished. See the same men three or four months later and you will scarcely recognise them. Their faces are lengthened and hollow, their eyes lustreless and drowsy, the erect bodies with sprightly gait have changed to shuffling decrepit-looking figures without tone. They are dirty and ill kempt, being too indolent or sick to trouble with refinements such as soap and water. The cause is not far to seek. They have come to make money and live on cheap and poor food. Malaria soon manifests itself among them, and in six weeks 75% of the gang may be down with fever during a snap of cold weather. They take it badly and are incapacitated for work much longer than natives. They recognise the value of quinine as a therapeutic agent, but will seldom continue it as a prophylactic. Consequently they have repeated attacks, and are practically never well or fit for a hard day's work. At the end of six months, the contract being complete, they return to Egypt with thinned ranks, with impaired constitutions, in fact for the most part physical wrecks. I had experience of two such gangs, and heard that the same had occurred with other gangs before my arrival, and this led me to advise the Managing Director to stop importing Egyptian labour. The same increased susceptibility to malaria was noticed among Egyptian overseers and time keepers. A dose of quinine once or twice a week did not act as an efficient prophylactic with them, and they had to take a daily dose of about 10 grains. It may be that the malarial parasite finds a more suitable host in the Egyptian, and is quick to take advantage of any intermission in quinine administration to develop rapidly. The conditions of climate and light in the Sudan approximate those in Egypt more than those in European countries, so that the greater susceptibility of the Egyptian cannot be explained by a lowered vitality from climatic conditions.

In this thesis, Gentlemen, I have endeavoured to convey to you a general view of the malaria problem in the Sudan from a Public Health standpoint. In order to deal with every point, and in the hope of maintaining interest in a somewhat unreadable subject, I have treated several sections somewhat superficially. Perhaps this may be excused when one considers that numerous points in the entomological section alone would each supply material for a thesis. I have purposely omitted giving opinions on a general system of treatment applicable to the whole country, as this largely is a matter for the decision of legislators who understand the finances of the country. The Sudan is still poor, and has not yet recovered from the wounds received under the Mahdist rule. Government can do but little at present in the fight against malaria, but as trade improves, and wealth increases, and towns spring up, the Public Health Service will surely advance as well. We can look forward to the time when each small town and each rural district will have its Medical Officer of Health, its Water Supply System, its Sanitary Department, its Mosquito Brigade, its Dispensaries and Hospitals all supported municipally. With improved conditions and better education of the people much may be expected, and future Sudanese people may look upon malaria much as we at present look upon small-pox, namely, that with ordinary care there is little fear of contracting the disease, and that although epidemics occur from time to time they can quickly be checked. All this will take time and money, and the hard work of many of our Profession. The following quotation from the Talmud seems a suitable summing up of the subject of this paper:-

> "The day is short and the work is great. It is not encumbent upon thee to complete the work, but thou must not therefore cease from it".

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