tively ineffective. Parathion in a wettable powder (15 per cent) was completely ineffective at 0.05 pound per acre, the highest dosage tested.

In the airplane tests treatments in forested areas with DDT-oil solutions at dosages of 0.05 to 0.22 pound of DDT per acre gave 85 to 95 per cent control, except in one plot treated in 600-foot swath intervals when 71 per cent control was obtained. In tests on open, eroded tundra and on mixed forest and open terrain, dosages of 0.09 to 0.35 pound per acre gave satisfactory control in only one of four plots.

The results obtained in these tests indicate that prehatching treatments, although not superior to conventional larvicide treatments, may be used for the control of arctic species of mosquitoes. The requirements for control, however, may differ greatly according to the type of terrain.

Literature Cited

Deonier, C. C., Fluno, J. A., and Nottingham, E. 1948. Preflooding treatments with DDT for mosquito control. Science 107:63–64.

Horsfall, William R. 1946. DDT used to control a rice-field mosquito, *Psorophora confinnis*. Jour. Econ. Ent. 39:723–725.

Roth, A. R., Yates, W. W., and Lindquist, A. W. 1947. Preliminary studies of larvicides on snow-water mosquitoes. Mosquito News 7:154–156.

Wisecup, C. B., Brothers, W. C., and Eide, P. M. 1945. Airplane spraying of rice fields with DDT to kill mosquito larvae. Jour. Econ. Ent. 38:686–688.

Wisecup, C. B., and Deonier, C. C. 1945. DDT for the control of *Psorophora* mosquitoes. Jour. Econ. Ent. 38:250–252.

Yates, W. W., and Gjullin, C. M. 1947. Prehatching applications of DDT larvicides on floodwater *Aedes* mosquitoes. Mosquito News 7:4–6.

ANOPHELES GAMBIAE MELAS CONTROL BY SWAMP DRAINAGE IN A COASTAL ZONE OF NIGERIA, BRITISH WEST AFRICA

LEONARD JAN CHWATT, M.D., D.T.M. & H.
Medical Department, Nigeria (B.W.A.)

The modern trend of malaria control is so dominated by the success of residual insecticides that a paper dealing with mosquito control by swamp drainage seems to be out of date. Nevertheless its aim will be reached if it provides a proof that even to-day the engineering methods of mosquito control based on the knowledge of the bionomics of the species involved and on a naturalistic approach to the technique of control can be highly successful.

At the very outset of this paper it must be made clear that the highly effective method of control of *A. gambiae melas* in West Africa was initiated and carried out by Dr. Alan B. Gilroy, O.B.E., who started the Lagos reclamation scheme as a military expediency in 1942 and expanded it by 1947 to its present size.

The Lagos reclamation scheme originated when the capital of Nigeria became one of the nodal points of the Transcontinental Ferry Service of the Royal Air Force. This service was organized to keep up the steady supply of front line aircraft for the Middle East theatre of war when the Mediterranean route was blocked. Fighter planes for the Middle East were shipped from Britain to West Africa in crates. Takoradi (Gold Coast) and Lagos (Nigeria) served as main bases for the assembly and test flights of these single-engined aircraft. From these two bases planes were flown across Africa in "air-caravans" consisting of 6–8 fighter planes following the leader—a light bomber with navigational facilities. The air route was across Nigeria, French East Africa, Sudan and then up the Nile valley to Cairo.

In 1943 and 1944 the Transafrican air

route saw an ever increasing flow of heavy aircraft of the U. S. A. Air Force.

As early as 1941 it became obvious that the Air Force base in Lagos, situated for the sake of convenience in the immediate vicinity of the harbour at Apapa, presented a great malaria risk to both the flying and ground personnel, as the harbour was within ½ mile of extensive mangrove swamps, breeding high numbers of mosquitoes.

In the early days of the war when residual insecticides were unknown, suppressive drugs and repellents in their infancy, and the malaria risk not fully appreciated, one had to rely on mechanical protection and on obsolete methods of malaria control.

"—500 blood-fed Anopheline females were captured day after day in each one-man tent of an anti-aircraft battery . . . 80% of all ranks of this battery contracted

Aerial view of part of the drainage scheme at Apapa showing the sluice gate, the bund with the facade drain and the inland system of channels.

malaria within 3 months of arrival at Apapa . . . the malaria morbidity rate at the nearbv R.A.F. station was 100 per 1000 per week for many weeks at a time" (Gilroy 1048).

It soon became very obvious that the extent and inaccessibility of the coastal swamps at Apapa presented a problem that could not be dealt with by piecemeal methods of control.

In mid 1942 it was decided to drain the main swampy area in the close vicinity of the airport. This pilot project was so successful and its beneficial effects felt so soon that the drainage work was extended to the neighbouring swampy islands within the 1-mile perimeter of the airbase and the harbour, and during the next two years well beyond this perimeter to areas where the entomological survey had revealed the breeding of the main malaria vector.

In 1945, encouraged by the lasting success and relative speed of this method of control, the Nigerian Government created a Malaria Unit working under the aegis of the Medical Department, obtained the services of the former military personnel in charge of the original reclamation scheme and extended this method of control to marshes situated within the Lagos township area. By 1947 the total area reclaimed by swamp drainage covered over 6 sq. miles.

2. Description of the Area

The climate of Lagos is typical of the Guinea type of equatorial climate. There is a "dry season" lasting from November to March, and two wet seasons; the "big rains" from May to July and the "little rains" throughout September and October. This double peak of the rainfall is due to the northward and southward swing of the equatorial low pressure trough in the wake of the zenithal sun. The average rainfall is 72 ins. of which about 60% falls during the "big rains".

The temperature is such that no month has a lower mean than 75° F. Accompanying the constant heat there is usually a high degree of humidity. In general the meteorological conditions during the year, except for two months during the peak of the dry season, are never unfavourable to mosquito breeding and to their survival in the adult stage.

The tides in the Lagos area are of interest since they contribute to the creation and maintenance of anopheline breeding. The ranges between high and low water neap tides average 2 feet. During the ordinary spring tides occuring twice a month, this range is increased to 3 feet. Equinoctial spring tides may occasionally reach the 5 foot mark.

Lagos is situated on an island between the Bight of Guinea and a large lagoon. To the north and west of the main island there are low sandspits and mangrove swamps; to the southeast and south there are several islands covered with mangroves and separated by a maze of creeks. The greater part of the foreshore presents vast stretches of flat lowland covered with a fringe of mangrove of variable width or with a dense and coarse mat of salt marsh grass.

The topography of the coastal area has a direct connection with its ecological aspects and with its importance as a mosquito breeding area. This relationship is not unlike that found by Sir M. Watson in the Malay Penisula in relation to *Anopheles umbrosus.* From the shore towards the mainland one can recognize 3 separate swamp zones which are sufficiently distinctive to be of great practical value. The first zone is a swampy foreshore with tongue-like projections along the mouth of the creeks and completely submerged by the diurnal high tides. The second zone has a slightly higher level (2–3 ft. above mean sea level) and is submerged twice monthly by the spring tides. The third zone is still higher (4–5 ft. above mean sea level) and submerged only twice a year by the very high equinoctial spring tides.

The typical vegetation of the first zone is composed of a tangle of branches and aerial roots of the red mangrove *(Rhizo-*

Inland fringe of an untouched mangrove swamp between the Rhizophora and Avicennia zones. Note numerous shallow pools breeding *An. gambiae melas.*

phora racemosa May) growing in a bed of black mud flats. The second zone is composed either of large patches of white mangrove (*Avicennia nitida* Jaq.) growing in patches of bare sandy soil or surrounded by salt marsh grass *(Paspalum vaginatum).* The white mangrove tree is very different from the red mangrove; while the latter consists mainly of a dense tangle of aerial stilt roots with hardly any trunk (as seen in Lagos), the *Avicennia* tree has a large and handsome crown supported by an often contorted trunk which is surrounded at the base by thousands of erect aerial rootlets sticking out of the ground.*

The treeless *Paspalum* grass-fields of the second zone extend for many acres in

* The West African mangrove species are also components of the South and Central American mangrove swamps. "Red Mangrove" is a general name for *Rhizophora.* The "White mangrove" of West Africa is called "black mangrove" or "honey mangrove" in the West Indies and in Florida. The "White Mangrove" of Florida is *Laguncularia racemosa* Gaertn, which occurs in West Africa only as a shrub.

the form of a thick, matted carpet hiding numerous shallow pools and puddles. Finally the third zone has a transitional type of vegetation composed of shrubs, salt water ferns *(Acrostichum aureum)*, and false date palms *(Phoenix reclinata)*.

The distinctive vegetation of each of these three littoral zones has an important bearing on the anopheline breeding as recognized in Sierra Leone by Thomson. (1945).

There is never any breeding in the first zone, distinguished by the presence of a continuous belt of the *Rhizophora* mangrove. On the other hand the second, spring-tide zone is responsible for most of the anopheline breeding. These breeding foci are numerous shallow pools round the *Avicennia* clumps or, to an even greater extent, widely scattered over the vast *Paspalum* grass flats, covered by the spring high water which remains there for 10–12 days during the dry season and is practically permanent during the wet season. In the third zone breeding places occur for a short time, mainly during the rainy season, although more permanent breeding may be found in patches where seepages are very pronounced.

3. MALARIA SITUATION

Like most of the British West Africa the area round Lagos shows the typical picture of malarial hyperendemicity. The transmission of the infection is practically perennial. The amount of malaria in the indigenous population assessed by repeated investigations of the child population, below the age of 10 years shows parasite rates varying between 75 and 90 per cent, with corresponding spleen rates varying between 60 and 80 per cent. Parasite rates in African children are usually higher than spleen rates, a fact which indicates a high degree of acquired immunity, particularly in the second quinquennium of age.

Plasmodium falciparum is the main parasite species with a frequency of 70 to 100 per cent of all infections. *P. malariae* is fairly common in African children—16 to 20 per cent of all infections. *P. vivax* and *P. ovale* are found in 0.5 to 2.0 per cent of African children. Mixed infections are common, the usual association is that of *P. falciparum* and *P. malariae*.

Malarial morbidity is difficult to assess in the African population. Child mortality due to malaria amounts to about 10 per cent of all African children admitted to the Lagos hospital. It seems to be the highest in the 2–3 age group. The actual amount of infant mortality due to malaria has not been reliably assessed. The malaria morbidity in the resident non-immune European population is difficult to assess on account of the general use of suppressive drugs. However the frequency of malaria in the transient non-immune population has been investigated during the war on the British Military personnel stationed in Nigeria during the war. In 1941 and 1942 the incidence of malaria per 1000 strength per year was 564 and 525 respectively.

4. THE VECTOR

Anopheles gambiae Giles, the main malaria vector throughout tropical Africa, is also the main malaria vector along the West Coast. The presence of a dark melanic variety of *A. gambiae* was first reported from the Gambia by Theobald (1903) who referred to adults with dark integument, with an additional fourth dark band on the maxillary palps and a considerable reduction of pale spots on wings and of pale rings on tarsi. Barber and Olinger (1931) working in Lagos brought to light the association between dark forms of *A. gambiae* and their breeding in brackish water along the coast. Ribbands (1944) found that in Freetown (Sierra Leone), of mosquitoes bred out of eggs laid by these four-banded melanic varieties, only about 30% of females had the additional band, the remainder showing no difference from typical *gambiae*. This author concluded that some coastal mosquitoes hitherto regarded as typical *gambiae* must be of the melanic variety, although they do not show any obvious signs of melanism. The same author decided that the high tolerance to salt water of the larvae of the melanic variety of *A. gambiae* and the character of the larval pecten warrant this variety to have a specific status of *A. melas*. This view was upheld by Thomson (1945) on the basis of differences between the eggs of *A. gambiae* type and *A. melas* and later (1947) supported by the same author on the basis of sterility of the male hybrids. The presence of an additional fourth band which was thought at first to be the distinguishing feature of *A. gambiae melas* is known now to be of little taxonomic importance. In the Lagos area in over 95% of *A. gambiae melas* this additional band is missing while on the other hand four-banded *A. gambiae* have been found several hundred miles away from the coast.

Many efforts to find an additional morphological feature that would allow the distinguishing of adult *gambiae* from adult *melas* have failed (Chwatt 1945).

It seems that the egg character is the only relatively reliable means of distinction. This applies of course only to gravid females. There is no way of telling the difference between wild males or non-egg laying females of the two mosquitoes. Some investigators consider that even the morphological differences of eggs of the two mosquitoes are not absolutely consistent and that they are not always constant in two successive generations. Thus they maintain that *A. melas* is merely a biological race of *A. gambiae*, different from the type form mainly by its ecological preferences, adaptation to sea water and geographical distribution (Chwatt 1945).

The problem of specificity of *A. melas* is still not completely solved and rather obscured again by the recent discovery in East Africa of *A. gambiae* with a typical structure of the egg and yet with a high tolerance to sea water.

The present position is certainly rather troublesome to a taxonomist who finds the borders between the concept of species and variety extremely vague. We may be dealing here with two sibling species (Mayr), the areas of whose distribution overlap and which are morphologically almost identical, but have specialized habitats and are reproductively isolated. We may on the other hand be dealing with a biological race; meaning by this a group isolated to some extent by food preferences, occurring in the same locality and showing differences in biology without any great structural differences. Whether we call *A. melas* a sibling species or a biological race depends to a great extent on whether the present taxonomic classification of Culicidae is based on a morphological concept or on a wider biological approach. It is true that the modern tendency among the geneticists is rather to stress the biological differences by separating into species all the groups that would previously have been regarded as varieties.

B. de Meillon (1947), in following the general attitude of the systematists of the Culicidae, regards *A. melas* as a variety and not as a distinct species. In view of the present still uncertain taxonomic position of *A. melas*, a trinomial nomenclature will be used in the present paper: *A. gambiae* type being designated as *A. gambiae gambiae* and *A. melas* as *A. gambiae melas*.

The work of Ribbands (1944) and Thomson (1945–47–48) has contributed very essentially to our present knowledge of the bionomics of *A. gambiae melas* which can be summarized as follows:

A. gambiae melas shows a distinct preference for breeding in salt water along the lagoons and tidal swamps of the West African coast where its geographical distribution overlaps with that of *A. gambiae gambiae* to a high degree. However, about one mile from the shore *A. gambiae gambiae* becomes the predominant, if not the only species.

As mentioned before, the breeding places of *A. gambiae melas* are almost entirely confined to parts of the coastal swamps flooded by high spring tides and characterized by the presence of *Avicennia* mangroves and by wide stretches of *Paspalum vaginatum*. *A. gambiae melas* can breed in water containing up to 47.6 gm. of sodium chloride per litre, which equals 150% concentration of sea-water in the

Bight of Guinea. The composition of the local population of the *A. gambiae* group varies according to the distance from the sea, to the topography of the area and also to the season of the year. While the peak of production of *A. gambiae gambiae* is related mainly to the rainfall, the peak density of *A. gambiae melas* is related to the tidal movements particularly during the dry season (Freetown, Sierra Leone). However, in areas where the tide range is small and the tidal movements not regular (Lagos), this relation is much less obvious.

More recent researches of Thomson's (1948) refer to the behaviour of *A. gambiae melas* and tend to stress the differences in the bionomics of the two components of the *A. gambiae* group. The indoor biting activity of *A. gambiae melas* is similar to that of *A. gambiae gambiae*: both show a marked increase after midnight and the peak of the biting cycle occurs between 04.00 hours and dawn. Both *A. gambiae gambiae* and *A. gambiae melas* show a tendency to leave the human habitations at dawn and to make use of outdoor shelters (overhanging earthbanks, ant-hills) but the latter mosquito is found in outdoor shelters much more often. There is some evidence that *A. gambiae melas* is less strictly anthropophilic than *A. gambiae gambiae* and that goats, pigs, and cows may attract it almost as much as man.

The investigation of the comparative infectivity of both *A. gambiae gambiae* and *A. gambiae melas* is based on identification of females from which egg batches have been obtained and examined prior to dissection of adults. This laborious method has shown that under equal conditions for acquiring an infection with *P. falciparum*, *A. gambiae melas* seems to be a less efficient vector than *A. gambiae gambiae*. (Thomson 1947.) This finding has recently (1948) been corroborated since it was found that in Lagos during 1947 the overall infectivity rate of salivary glands of *A. gambiae gambiae* was 11.2 or about 40% higher than the corresponding rate for *A. gambiae melas* (7.2 per cent).

This observation combined with dissimilar trends of the seasonal natural infectivity of both mosquitoes suggests that there may be some still unknown differences in their behaviour. However, there is little doubt that *A. gambiae melas*, whatever its taxonomic status may be, is a formidable vector of human malaria along the coast of West Africa.

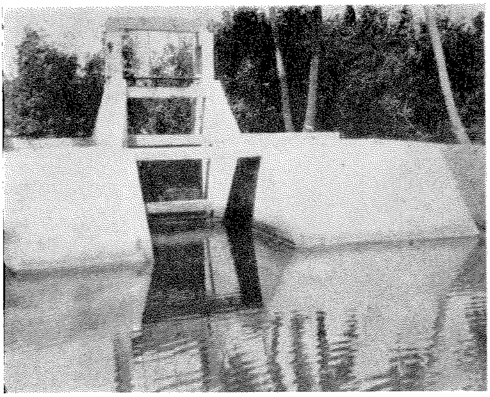
5. Principles of Drainage

These have not been very different from the methods of swamp drainage first used by Sir Malcolm Watson on Carey Island in Malaya forty years ago. The rationale of the method is well described by Herms and Gray (1941) who classify it as a reclamation type of drainage of salt water swamps. It consists of (a) building a sea-wall (also known as bund or dyke) which encloses the low-lying swamp and prevents the tidal waters from flooding it, (b) collecting the water in the swamp in a system of channels which lead to (c) a controlled outlet in the form of a sluice gate. The sluice gate open at the low tide permits the outflow of water from the system of drains into the creek. The gate is closed at the high tide and prevents the inflow of water when the water level outside the dyke is higher than the water level inside it.

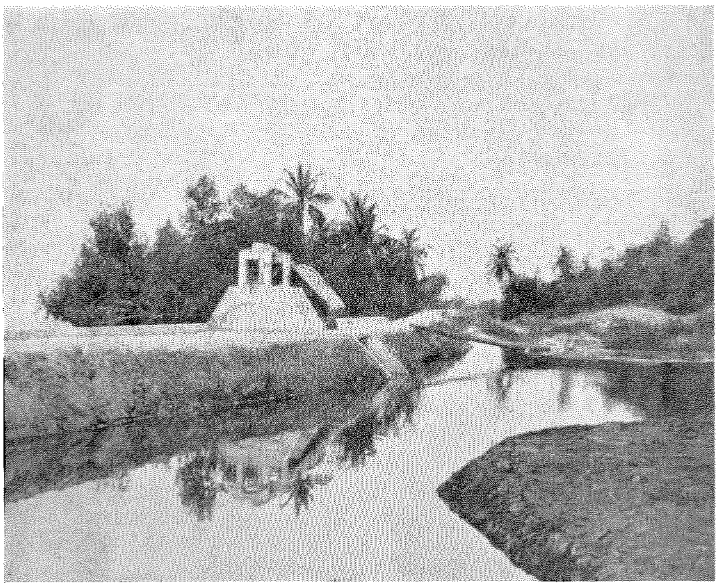
A detailed description of the technical side of the Lagos swamp drainage scheme will be found in Gilroy's outstanding monograph (1948). However a brief summary of it will give an idea of the type of work accomplished with great success.

Although the principle of the reclamation type of swamp drainage is well known, its adaptation to the small tidal range in Lagos was novel, since one disposed of only a small waterhead to run off the impounded water from the flat swampland to the creek.

The bund built of peaty soil excavated from the facade drain follows the line of the foreshore and is set about 50 ft. inland from it. Its height is such that it will prevent even the highest spring tides from passing over. It has a top width of 6 ft. and a protective berm on the seaward side to reduce the effect of sea-erosion.



Concrete, hand-operated sluice gate.



Sluice gate, the bund and the facade drain. Note behind the sluice gate the palm-thatched hut of the operator and the palm-trunk bridge.

The system of inland channels depends entirely on the topography of the area. As a general rule the facade drain is connected with the contour or hill-side drain dug round the inland limit of the swamp. All isolated higher levels are also provided with contour drains and the vast stretches of Paspalum grass are drained by small herring-bone or separate drains.

The land in the *Rhizophora* and *Avicennia* zone has a fairly uniform level and no gradient needs to be given to the channels which are excavated to a uniform depth of 4 feet, viz. about 9 ins. below the lowest level of the run-off. They always contain water and have clean edges and suitably sloped walls. Three types of drainage pattern have been used; (a) complete drainage with the object of controlling breeding in the shortest possible time, (b) minimal drainage, where main drain can be left to gradually dry out the bunded swamp and (c) preliminary drainage carried out as an immediate expediency until the swamp floor has partly dried and hardened (Gilroy 1948). The possibility of designing a system of drains without any gradient greatly facilitated the task and permitted the use of unskilled manual labour on a large scale. The tendency towards the minimal drainage greatly increased the speed of work.

Four types of drains were used: (a) the facade drain (10 ft. invert) from which the spoil provides material for the building of the parallel bund, (b) main drains (7 ft. invert) which lead the internal system of channels towards the sluice gate, (c) subsidiary drains which drain the low-lying ponds into the nearby main channels and (d) contour drains which are really small scale foot-hill drains since they follow the margin between swamp and high land. The bottom width of the two last mentioned drains is 3′ 6″.

The concrete hand-operated sluices are of an original design based on an approximate estimate of 1 foot of width of sluice to every 40 acres of swamp. The most important feature of the sluice—the height of the sill in relation to the tides—is set at about 3 feet below the level of the lowest recorded tide.

The operation of the drainage system is carried out throughout the year and varies slightly according to the season. During the rainy season the sluice is opened twice daily at every low tide and even after a heavy storm the water accumulated in the system of drains can be easily led off within a few hours. During the dry season from October to December tides often do not fall to the usual level for days and the regular rhythm of opening the sluice gates cannot always be kept up. This variation of tide ranges and times is quite unpredictable in a maze of creeks surrounding the swamps and must be judged by the sluice gate operators.

The extent of the Lagos scheme can be seen from the following data. Lagos has a population of about 200,000 Africans and several thousands of Europeans and is a busy colonial port. The urban district of it has an area of 24 square miles, of which about 7½ square miles were mosquito breeding tidal swamps. Since 1943 an average of 1000 acres a year have been drained and the scheme is now completed. Of the remaining 1½ square miles of swamps 1 square mile is being reclaimed by sand filling, ½ square mile of swamp is unsuitable for drainage on account of the limited tidal range and must eventually be dealt with by different methods. The summary of the progress of the scheme is given in the following table.

6. EVALUATION OF RESULTS

Coastal swamps breeding *A. gambiae melas* cover about ¼ of the total area of the town of Lagos and the control of this mosquito by swamp drainage does not involve dealing with *A. gambiae gambiae* which breeds, as it is well known, in borrow pits, puddles, wells, pools and other rather small collections of water. The control of *A. gambiae gambiae* in Lagos is carried out by the local Health Office, by routine larvicidal methods based on the division of the whole township area into 35 zones, to each of which is as-

TABLE 1. Summary of the Progress of the Lagos Swamp Drainage Scheme.

Year	Area in acres	Length of bund	Length of drains	Number of sluice gates
1943	610	3 miles	16.1 miles	2
1944	1093	6.2 miles	30.7 miles	6
1945	909	8.6 miles	42.1 miles	7
1946	1583	2.9 miles	41.5 miles	5
Total	4195	20.7 miles	130.4 miles	21

signed a permanent oiling team. Each zone is divided into 5 oiling-sectors, each of which represents the daily task of the team.

The entomological section of the Malaria Unit was assigned to collect the data from the whole of the township area. However only the results pertaining to the control of *A. gambiae melas* need to be reported here.

This section was divided into two parts: (a) Adult Capture Service and (b) Larvae Check-Control Service which dealt with the imagines and larvae of the local malaria vectors respectively.

(a) *Adult captures:*

The evaluation of the control of *A. gamgiae melas* was based on a regular weekly collection of adult mosquitoes from 275 selected Capture Stations suitably distributed over the controlled area. These stations are houses inhabited by the African population where on fixed days of the week trained collectors capture all adult mosquitoes found inside the rooms in the early hours of the morning. This is carried out by the "spray-floor sheet" technique based on spraying the rooms with suitably calculated (1 fl. oz. per 1000 cubic feet) amount of 0.1% pyrethrum/kerosene spray and collecting all dead mosquitoes found on a standard size sheet spread on the floor.

Mosquitoes collected from the Capture Stations are identified in the laboratory, dissected for sporozoites in the salivary glands and the results of collections recorded.

The relative numbers of collected malaria vectors are assessed by means of the Average Anopheles Density index (A.A.D.) separately for each zone. The A.A.D. index represents the mean number of female *Anopheles* found in one room of a Capture Station per day. This index calculated for each zone represents the daily mean of all Capture Stations indices within a particular zone during the month.

The effect of swamp drainage on the mosquito density in any coastal zone can be best shown by tabulating the mean and peak figures recorded from two typical zones viz: Apapa and Meridian Point during the period covering the conditions before and after drainage of zonal swamps breeding *A. gambiae melas*.

(b) *Larvae Check Control:*

The amount of anopheline breeding in uncontrolled stretches of swamps and in reclaimed areas was checked over a period of 3 years. Collections of larvae

TABLE 2. Average *Anopheles* density in two typical *A. gambiae melas* breeding areas before and after completion of the drainage scheme.

APAPA	Mean A.A.D. per room	Max. A.A.D. per room	MERIDIAN POINT	Mean A.A.D. per room	Max. A.A.D. per room
1942 Before drainage	47.0	500 ?		—	—
1943 During drainage	12.0	28.5	1944 Before drainage	25.0	41.5
1944 After drainage	3.7	7.2	1945 After drainage	2.8	6.0
1946 III qtr.	1.8	5.7	1946 III qtr.	0.7	3.8
IV "	0.25	0.5	IV "	0.5	0.7
1947 I qtr.	0.2	0.3	1947 I qtr.	0.6	0.9
II "	1.2	1.7	II "	2.1	2.7
III "	2.2	3.8	III "	1.2	2.0
IV "	0.5	0.8	IV "	0.3	0.4

were made systematically at weekly intervals by supervised trained personnel.

The whole area is divided into zones. Each of them has a permanent team, which covers the zone assigned to it within one week, working every day in one of the five sectors into which the zone is divided.

The method of sampling is that of using a close-mesh standard size larval net which is swept at 4″ below water level at both edges of drains and along the uncontrolled stretches of swamps. Every 100 feet the net is emptied and rinsed in a dish and the numbers of *Anopheles* larvae and their respective instars recorded.

Owing to the war-time emergency it was not possible to carry out a pre-control larval survey of the drained areas and the figures for comparative pre-and-post control larval densities are not available.

However, two typical coastal salt water swamps, Mekunwen and Victoria which are being slowly filled in by sand-pumping are still in an almost virginal state. They offer an excellent comparative picture of the anopheline breeding activity in a virtually uncontrolled zone.

TABLE 3. Mean number of anopheline larvae collected daily per acre of water-surface in drained and undrained areas in Lagos.

	1946	1947
Drained coastal swamps	11.4	28.4
Undrained coastal swamps (Mekunwen & Victoria)	578.2	1734.8

The use of larval nets swept along the edge of the drains gives also an idea of the anopheline density per one mile of drain. This figure varies according to the season to the width of the drain and to its distance from the sluice gate as shown in the following table, covering the period 1946–1947:

TABLE 4. Mean number of anopheline larvae per 1 mile of drain, 1946–1947.

	Rainy season	Dry season
Main drain	1.2	3.0
Subsidiary drain	7.2	14.6
Contour drain	15.4	68.8

The investigation of the respective percentages of larval instars has revealed that well over 50% of anopheline larvae found in the drains are first or second instars while third and fourth instars of anopheline larvae were much less frequent. Pupae were found infrequently as shown in the following table.

TABLE 5. Respective percentages of various instars of anopheline larvae collected in all drainage channels during 1947.

	Instars I & II	Instars III & IV	Pupae
1st quarter 1947	75	25	0
2nd "	51	48	1
3rd "	50	47	3
4th "	54	44	2.5

The increase of larval breeding and the appearance of pupae in the distant parts of the channel system during the period of high tides about the middle of the dry season can be explained by the decrease of the controlling factor of fluctuating water level combined with the more difficult access of fish to the shallow stagnant drains.

Regular weekly returns of results of routine larval surveys are always of great importance but particularly during this period. Any breeding focus found in the drained area is marked in the field (after being treated) and subsequently plotted on the plan of the respective drainage zone. This permits the detection of any faults in the maintenance of channels.

"A most satisfying experience is to see the sun-cracked dry bottom of a lake that a week before was crossed by a canoe" (Gilroy 1948).

Immediate results of swamp drainage are seen soon after the exclusion of tides from the swamp and consist of quick drying up of the land followed by cracking of the mud which forms the bottom of the swamp floor. This is soon followed by changes in vegetation. Rhizophora mangroves are visibly affected by the new conditions and die out within a year. The growth of Avicennia is not affected nor is Paspalum. New plant life hitherto limited to the higher contours appears within the next two years and soon the whole vegetation of the drained area shows a striking difference from what it was prior to the exclusion of the tidal waters.

With the rapid exclusion of their usual breeding places the extensive breeding of *A. gambiae melas* disappears completely within a week. The only water that remains on the drained land is the brackish water in the system of drains.

"In the original designing of the Lagos scheme it was taken for granted that *A. gambiae melas* would breed in the drains and that regular larviciding would be required. The possibility or even the certainty of anopheline breeding in drains would not be a valid reason against swamp drainage. In an undrained swamp breeding occurs over many hundreds of acres even though it may be detected and reported only at the margins. On the other hand when the swamp has been controlled all surface water is contained in the channels where it is readily accessible and being free from vegetation it is open to the action of larvicides should they be necessary" Gilroy (1948).

The freedom of well maintained but *otherwise untreated* drains from any significant amount of larval breeding is probably due not to one but to several combined factors. (a) Complete alteration of the breeding habitat by temporary impounding of any available water in relatively deep channels without any marginal vegetation.

(b) Cyclical fluctuation of water level in the channel during the period of discharge through the open sluice gates.

(c) Increased activity of several species of indigenous larvivorous fish which have a free access even to the farthest points of the drainage system during most of the year.

Of several species of small Gobidae, Cichlidae and Cyprinodontidae always present in the drains at least two proved to be very active predators. *Eleotris lebretoni* ("Kusukusu" in Yoruba language) and *Haplochilus spilanchen* ("Majoju") are of very definite larvivorous value as found in experiments carried out in the laboratory and in the field.

The final question arises whether the control of *A. gambiae melas* by swamp drainage was justified from practical point of view since perhaps the same good or even better results could have been achieved by other modern methods of control. The question thus posed does not take into account the value of dewatered land, which can be and has already been used for agricultural purposes and for afforestation but pertains only to the public health point of view.

To answer it we must examine the purely technical aspect of other malaria control measures possible in local conditions. As pointed out by Gilroy (1948) it was found that the use of larvicides in an undrained swamp is time consuming, difficult, expensive and not very effective. Virgin salt-water swamps are inaccessible flats with a soft, muddy soil crisscrossed by numerous small creeks and deeper streams. Exceedingly numerous anopheline breeding foci are irregularly scattered and hidden among the stretches of coarse salt marsh grass which presents a formidable obstacle to the traditional techniques of oiling or dusting with larvicidal dusts.

The use of residual DDT for spraying of houses must be ruled out since there are only few human habitations within or in the vicinity of the main breeding area and spraying of these primitive dwellings would not or very little decrease the anopheline population.

The initial aim of the described method of swamp drainage was simply to canalize an otherwise uncontrollable zone in order to deal with the malaria vector by chemical larvicidal measures. The discovery of the specialized breeding habits of *A. gambiae melas* provided a basis for planning a combined hydrotechnical and naturalistic approach to the problem and offered a possibility of an effective "species control" bordering on local eradication of one of the main malaria vectors.

Bibliography

1. BARBER, M. A. AND OLINGER, M. T. (1931). Studies on malaria in S. Nigeria. Ann. Trop. Med. and Par. 25, 461.

2. BOTHA DE MEILLON. The Anophelini of the Ethiopian Geographical Region. South Afr. Inst. for Med. Res. Johannesburg 1947.
3. CHWATT, L. J. (1945). Studies on the melanic variety of *A. gambiae* in S. Nigeria. Journ. Trop. Med. and Hygiene 48, 22.
4. CHWATT, L. J. (1945). The morphology of the pharyngeal armature in *A. gambiae* and var. *melas* from S. Nigeria. Ann. Trop. Med. and Par. 39, 124.
5. GILROY, A. B. Malaria Control by Coastal Swamp Drainage in W. Africa. Ross Inst. of Trop. Hygiene. London 1948.
6. GILROY, A. B. AND CHWATT, L. J. (1945). Mosquito Control by swamp drainage in the coastal belt of Nigeria. Ann. Trop. Med. and Par. 39, 19.
7. HERMS, W. B. AND GRAY, H. F. Mosquito Control. New York: Commonwealth Fund. London: Humphrey Milford. (1940).
8. RIBBANDS, C. R. (1944). Differences between *A. melas* and *A. gambiae* I. Ann. Trop. Med. and Par. 38, 85.
9. RIBBANDS, C. R. (1944). Differences between *A. melas* and *A. gambiae* II. Ibid. 38, 37.
10. RIBBANDS, C. R. (1944). The influence of rainfall, tides and periodic fluctuations on population of *A. melas*. Bull. Entom. Res. 36, 395.
11. ROSEVEAR, D. R. (1947). Mangrove swamps. Farm and Forest 8, 23.
12. THOMSON, R. C. MUIRHEAD (1945). Studies on the breeding places and control of *A. gambiae* and *A. gambiae* var. *melas* in coastal districts of Sierra Leone. Bull. Entom. Res. 36, 185.
13. THOMSON, R. C. MUIRHEAD. (1948). Studies on *Anopheles gambiae* and *A. melas* in and around Lagos. Bull. Entom. Res. 38, 527.
14. THOMSON, R. C. MUIRHEAD (1947). Recent knowledge about malaria vectors in West Africa. Trans. Roy. Soc. Trop. Med. 40, 511.
15. TREDRE, R. F. (1946). The role of *An. gambiae* var. *melas* in the transmission of malaria in the vicinity of Freetown estuary Sierra-Leone. Ann. Trop. Med. and Par. 40, 380.

OBSERVATIONS ON THE USE OF TOXIC BRIQUETTES FOR MOSQUITO CONTROL

TED G. RALEY
Manager

AND

EDWARD D. DAVIS *
Entomologist, Consolidated Mosquito Abatement District, Fresno County California

While the idea or theory of mosquito control by utilizing fixed dispensers or briquettes impregnated with insecticides is not new, there has been little investigation of this method of mosquito control carried on in the San Joaquin Valley of California. This paper will relate the experiences and observations gathered by the Consolidated Mosquito Abatement District, Fresno County, California, where extensive experimental work was conducted with briquettes for larval control during the 1948 hatching season. Several styles of briquettes were used in the test work; no attempt, however, is made to compare one with the other. Instead, a general discussion relative to work performed with briquettes is set forth.

The desirability for some method of larval control other than spraying, either hand or power, became apparent soon after the formation of the district in 1946. Included in the 1000 square mile area that must be regularly patrolled for mosquito sources are a vast number of small but prolific larval hatching areas that must be constantly watched. Many of these sources take little time to treat for larvae; their great number, however, requires much of the operator's time that could be used to better advantage on larger problems. While many of the sources have been entirely eliminated and others will

* Mr. Davis is now manager of the Fresno Mosquito Abatement District, Fresno, California.