SOME FACTORS CONTRIBUTING TO THE PAUCITY OF YELLOW FEVER IN THE ASHANTI REGION OF GHANA

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1.0 ABSTRACT

Mosquitoes occurring in an urban and two rural areas of Ashanti were identified in a study to find out why the Ashanti Region of Ghana has nearly always escaped Yellow Fever epidemics that have swept through the country since 1900.

Several species of the Yellow Fever mosquitoes were encountered, namely Aedes (Stegomyia) aegypti Linnaeus, Aedes (Stegomyia) africanus Theobald, Aedes (Stegomyia) luteocephalus Newstead, Aedes (Stegomyia) vittatus Bigot. Other mosquitoes were Culex (Culex) decens Theobald, Culex (Culex) thalassius Theobald, Culex (Lutzia) trigripes Granpre, Anopheles gambiae S.I. and Toxorhynchites brevipalpis Theobald.

The mean Aedes mosquito indices throughout the research work were as follows: Biting rate 0.53; House Index 8.85; Container Index 3.67 and Breteau Index 11.45. Although the values are considered capable of promoting the transmission of Yellow Fever, they are remarkably lower than the International Threshold values of Biting rate 2; House Index 35; Container Index 20; Breteau Index 50 and therefore unlikely to promote Yellow fever transmission by Aedes aegypti in the Urban cycle.

Rainfall and Relative Humidity (%) at 1500 hours GMT were remarkably correlated with larval and Biting indices.

The low larval indices which may have reflected on the low man-vector contact rates were probably influenced by the vast distribution, resilience and predatory propensity of Toxorhynchites brevipalpis. Other minor predators found on the Aedes mosquito were Culex (Lutzia) tigripes, Notonecta, Nepa sp. (Water scorpion), Hydrometra (Water Stick), Belostoma (giant water bug) and Lispa

(anthomyid fly). Toxorhynchites preferred feeding on Aedes aegypti to other mosquito species such as Culex decens and Anopheles gambiae.

No Toxorhynchites were found in other regions bordering Ashanti where Yellow Fever epidemics has been recorded.

2.0 INTRODUCTION

Yellow Fever is an infectious disease caused by an arbovirus in many tropical countries of Africa and America. In America, it is found between the parallels 10°N and 20°S and in Africa between the parallels 15°N and 10°S (WHO, 1971). In the past, epidemics were experienced in temperate climates of America and Europe where the virus was transmitted during the summer in areas colonized by Aedes (Stegomyia) aegypti (Linnaeus) (WHO, 1971).

Yellow fever causes degeneration of the tissues of the liver and kidneys. Symptoms include chill, headache, pains in the back and limbs, fever, vomiting, constipation, a reduced flow of urine which contains a high level of albumin and jaundice. Yellow fever often proves fatal and attacks both male and female. The disease may present two distinct epidemiological patterns, namely, the Urban type and the Jungle or Sylvan type.

In the classical Urban type of Yellow fever, man serves both as the natural vertebrate reservoir and amplifier and, therefore, the source of infection to susceptible mosquitoes. The domestic mosquito Aedes aegypti, which breeds predominantly in small collections of water in the vicinity of human dwellings, is virtually the exclusive natural vector.

In the Jungle or Sylvan type of Yellow fever, with particular reference to Africa, the Yellow fever virus is maintained by a natural cycle involving wild arboreal primates, primarily Cercopithecus and Colobus monkeys, and mosquitoes. The most important mosquitoes involved in this type of Yellow fever cycle are Aedes (Stegomyia) africanus (Theobald) and Aedes (Stegomyia) simpsoni (Theobald). Aedes africanus is known to bite monkeys readily (Haddow and Dick, 1948) and is a dominant forest canopy mosquito (Smithburn et al.

1949) which maintains Yellow fever cycle with non-human primate hosts and occasionally causes Yellow fever outbreaks when it bites man. Its main biting activity occurs shortly after sunset (Haddow et al. 1947) and also at ground level at dawn (Haddow, 1965). The fact that it bites man readily (Haddow and Dick, 1948; Bang et al. 1980; Bang et al, 1983) in most parts of its distribution range may indicate that man may become infected in situations such as when collecting firewood, water, or when felling trees. In the latter case, infected mosquitoes inhabiting the forest canopy may be brought to ground level and may come into contact with man in the forest. Another situation in which man may be involved in the Sylvan cycle is when infected monkeys raid plantations bordering the forest. In such situations, the biting species such as Aedes simpsoni living and breeding mainly in banana plantations, and in edges of forests near ground level (Haddow, 1945) maintains the Sylvan-Urban cycle.

Yellow fever is endemic throughout West Africa (Boyce, 1911) and in Ghana, records of the number of cases (morbidity) and deaths (mortality) for the past 20 years (WHO, 1985) confirm that this is so. Yellow fever epidemics in Ghana occur almost entirely north or south of the rain belt (Scott, 1965) and are considered to be of the urban type (Agadzi et al. 1984). The hyperendemic core of the diseas (Fig. 1) may be found in an area bounded by a line connecting Axim, Tarkwa and Kpando and another line joining Accra, Oda, Kibi, Akuse and back in Accra (Scott, 1965). The epidemics in the Southern sector of Ghana recur every 10-12 years and mostly during the rainy seasons (Scott, 1965).

The literature shows that of all the Yellow fever epidemics which developed in Ghana in 1977, 1978, 1979 and 1983 (Agadzi et al, 1984; WHO 1985; Addy et al. 1986, Baffoe-Wilmot, 1987) none

was recorded in the Ashanti Region. An earlier work by Scott (1965) on Yellow fever in Ghana between 1900-1960 gave the same report.

This study was undertaken in Kumasi and the two neighbouring towns of Akropong and Ejisu all in the Ashanti Region.

The objectives of the study were:

1. To identify and catalogue the various species of Aedes mosquitoes that may occur in Ashanti Region.
2. To ascertain possible factors, both physical and biological, that may influence vector population densities, and
3. To use the information obtained in explaining the paucity of Yellow fever epidemics in the Ashanti Region.

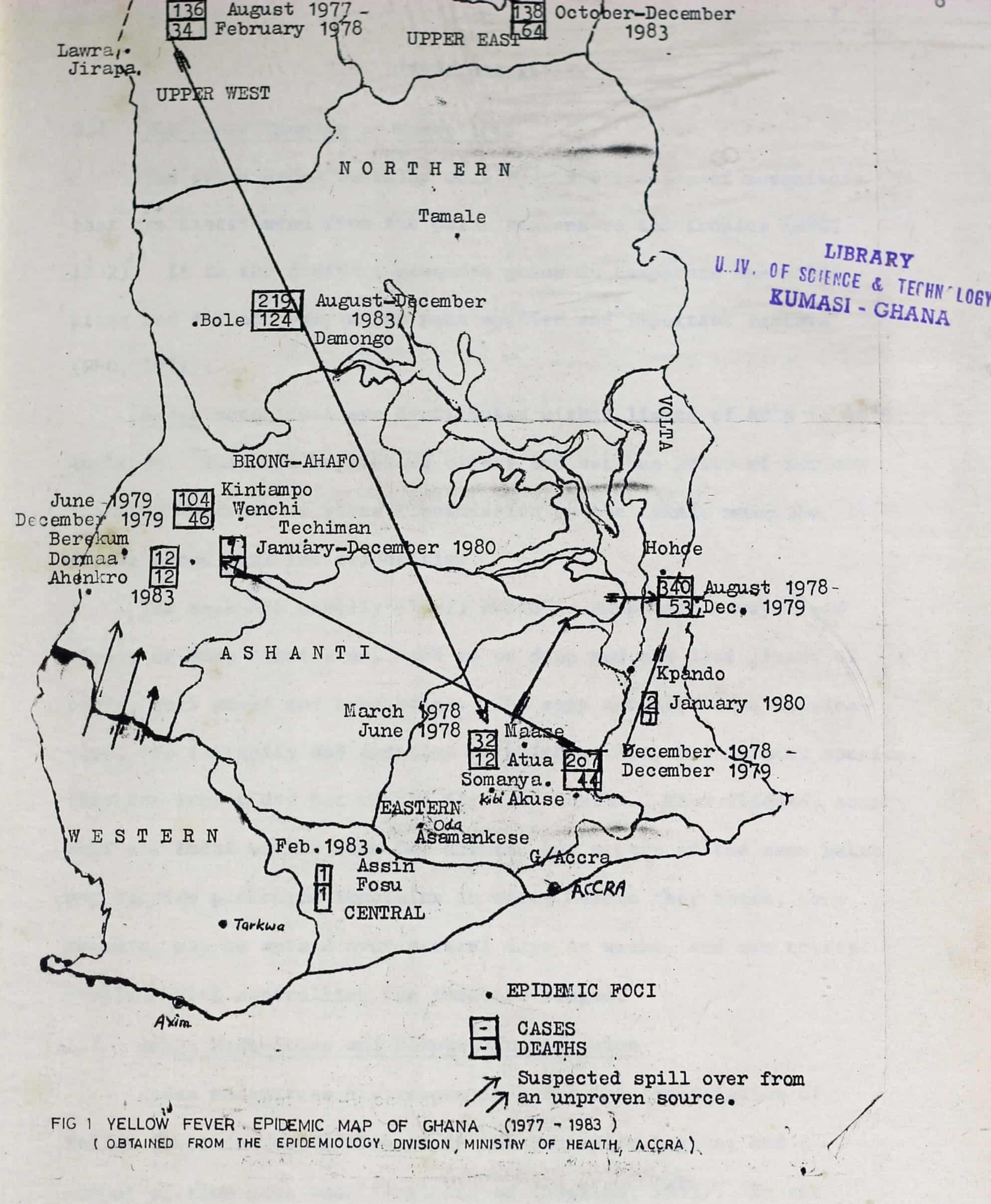

FIG 1 YELLOW FEVER EPIDEMIC MAP OF GHANA (1977 - 1983)
(OBTAINED FROM THE EPIDEMIOLOGY DIVISION, MINISTRY OF HEALTH, ACCRA)

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3.0 LITERATURE REVIEW

3.1 The Aedes Species of Mosquitoes

The genus aedes contains more than 500 species of mosquitoes that are distributed from the polar regions to the tropics (WHO, 1972). It is the dominant mosquito genus in temperate and cold areas and include many major pest species and important vectors (WHO, 1972).

Aedes mosquitoes are distributed within limits of 40°N to 40°S latitude. They can be vicious biters and serious pests of man and livestock because of virus transmission by the female mosquito during blood meal for oviposition.

The eggs are usually black, avoid in shape and always laid singly on damp substrates, such as on damp mud and leaf litter of pools, rock pools and tree holes. The eggs can withstand dessication, the intensity and duration of which varies, but in many species, they can remain dry but viable for many months. When flooded, some eggs may hatch within some few minutes but others of the same batch may require prolonged immersion in water before they hatch, thus hatching may be spread over several days or weeks, and can create problems with controlling the immature stages.

3.2 Aedes Mosquitoes and Disease Transmission

Aedes mosquitoes are responsible for the transmission of Yellow fever in West Africa or in the Ethiopian Region; and a number of them have been incriminated (hopkins, 1952). In the 1955 epidemic in Kintampo Region of the Northern edge of the forest, considered to be jungle Yellow fever, Aedes aegypti was absent or rare but two non-domestic potential vector species were present,

Aedes africanus and A. luteocephalus (Boorman and Potterfield, 1957). In Africa, Aedes leucocelaenus is an efficient vector (Service, 1979). Also in the epidemic of 1983 in Burkina Fasso (Upper Volta) the vectors involved were Aedes furcifer and Aedes metallicus (Baudon et al. 1984). Aedes africanus which was shown by Phillip (1929) to transmit Yellow fever under laboratory conditions is known to bite monkeys and man readily (Haddow and Dick, 1948), and is a dominant forest canopy mosquito (Smithburn et al. 1949) which maintains a true enzootic and on occasions epidemic Yellow fever cycles.

3.3 Susceptibility of other Species of Mosquitoes to Laboratory Infection with Yellow Fever Virus

Although about 4 species of Aedes stegomyia and 2 species of Haemagogus transmit Yellow fever virus in nature, the following mosquitoes were susceptible to laboratory infection of Yellow fever virus: Eretmapodites chrysogaster, Taeniorhynchus africanus, Culex thalassius, Trichoprosopan frontosus and Sabethes spp (WHO, 1967).

3.4 Yellow Fever - The Disease - Historical Background

Yellow fever was first known in the 17th century with the first outbreak reported from Barbados in 1647, probably carried there by ship from Africa (Simpson, 1978). It was later recognized as a disease entity in the Island of Guadeloupe in the same century (Du Tertre, 1667-1671). A few years later, Lopez de Cogulludo (1688), described an epidemic with similar characteristics in Yucatan.

Although informations are in favour of the origin of the disease being the West Coast of Africa (Finlay, 1941), the exact geographical origin of Yellow fever remains a subject of much debate.

Medical historians have discussed at some length where the disease might have originated but there has been no agreement among them whether it was carried from the Americas to Africa or the other direction (Scott, 1965). The disease occurs only in tropical (West and East) Africa, Central America, and the Northern half of South America (Strode 1951, Kirk, 1953; Davey and Lightbody, 1956). It has not been found in either Asia or Australasia.

In 1881, Dr. Finlay, a physician in Cuba suggested that Yellow Fever was conveyed from man to man by the bite of the mosquito Aedes aegypti (Scott, 1965; Rhodes and Van Rooyen, 1968).

In the late 1890s large numbers of American soldiers died of Yellow Fever in a military campaign in Cuba, and from the observations by the United States Army Yellow Fever campaign in 1900 presided over by Major Walter Reed (Scott, 1965, Rhodes and Van Rooyen 1968) it was shown that:

1. mosquitoes, principally, Aedes aegypti were vectors of Yellow Fever after an extrinsic incubation period of 12 days, and
2. Humans, were both the definitive hosts and the natural reservoirs for Yellow fever.

Eradication of Yellow fever from selected areas in Cuba in 1901 and Panama in 1902 by elimination of Aedes aegypti adult mosquitoes from domestic situations under the direction of Major William Golgas, confirmed the existence of the man - mosquito cycle of urban Yellow fever (Scott, 1965; Rhodes and Van Rooyen, 1968); but transmission studies conducted after the isolation of the Yellow Fever virus in Africa revealed that the Sylvan mosquito such as Aedes africanus also transmitted the Yellow fever virus.

In Ghana (formerly Gold Coast) as well as many other West African countries, Yellow Fever was thought to be absent or at least non-endemic, so that Yellow Fever surveillance was not undertaken in this region until 1910, when as a result of a series of outbreaks involving most of the countries along the West African coast from Senegal to Nigeria, the British Government sent Sir Rubert Boyce to investigate. In his report, he stated that there was no doubt that the Yellow Fever disease was endemic throughout West Africa (Boyce 1911). This observation was confirmed later by Hall (1912); Horn (1913) and Anon (1913-1916).

Our knowledge of the epidemiology of Yellow Fever in Ghana comes largely from the work of the Rockfeller Foundation's Yellow Fever Team, based in Yaba near Lagos, Nigeria, which started its work in 1925. The aim was to find the cause and means of transmission and to map out the endemic areas. Prior to 1925 and up to 1927, the epidemiology of Yellow Fever was based on a generally accepted belief that man was the only susceptible vertebrate host and that the mosquito, Aedes aegypti was the sole vector. It led to the view that Yellow Fever could only exist in places where this mosquito vector and naturally man, the susceptible host, were both present in adequate numbers. This view was supported by the repeated demonstration that Aedes aegypti control resulted in the prompt disappearance of the disease. However, when in Brazil, it was found that Yellow Fever did not disappear after many years of effective control in principal cities, this conception had to be reviewed and the reason for the failure investigated.

It is now known that Yellow Fever is endemic and widespread in sparsely populated regions under conditions which indicate that

neither man nor the mosquito Aedes aegypti is essential in the insect-vertebrate cycle of infection, which disease type has come to be known as "Jungle Yellow Fever" (Mahaffy 1949).

Yellow Fever has occurred in Africa either as sporadic cases of Jungle Yellow Fever, mainly in the forest area or as outbreaks, mainly in savanna areas. It has been found that in addition to Aedes aegypti, at least 13 species of mosquitoes are able to transmit Yellow Fever and some of these potential vectors have been captured during epidemics (Hamon et al. 1971). Monkeys may not be the actual reservoirs but they are at least responsible for enhancing the circulation of the virus (Monath and Kemp, 1973).

3.5 Epidemiology of Yellow Fever in Ghana

Incidences of Yellow Fever epidemics over the years are related among other things, to Relative Humidity and Rainfall (Table 1). The Aedes mosquito is responsible for its transmission and outbreak.

It has been reported by the World Health Organization that the number of Yellow Fever cases (morbidity) and deaths (mortality) during the last 20 years in Africa with particular reference to this country shows that Yellow Fever is endemic in Ghana (WHO 1985) and that during the Yellow Fever epidemics which developed in Ghana in 1977, 1978, 1979 and 1983 (Agadzi et al. 1984; WHO, 1985; Addy et al 1986; Baffoe-Wilmot, 1987) none of these Yellow Fever epidemics occurred in regions bordering on the Ashanti region.

3.5.1 Vector Species Involved

The most important vector species known to be involved in the transmission of Yellow Fever in Ghana are Aedes aegypti (Burton et al. 1964), A. luteocephalus and A. africanus (Boorman et al, 1957). Other Aedes species, namely A. vittatus, A. simpsoni and

TABLE 1 REGIONAL DISTRIBUTION OF YELLOW FEVER CASES AND DEATHS FOR THE EPIDEMIC PERIODS 1963-70, 1977
AEDES AEGYPTI INDICES COMPARED WITH ASHANTI REGION WHERE THERE WERE NO YELLOW FEVER EPIDEM

EPIDEMIC PERIOD	REGION	LOCALITY	No OF CASES	NO OF DEATHS	CASE FATALITY RATE C.F.R.	RAINFALL (MM)	RELATIVE HUMIDITY % 0900 GMT	1500 GMT	TE M
1963 — 1970	NORTHERN	PONG TAMALE	5	3	60·0	105 · 4	67	48	34
	UPPER EAST	BOLGATANGA	49	8	16·0	99 · 9			
		NAVRONGO	61	12	19·7	76·3	57	39	34
	UPPER WEST	NANDOM	40	11	27·5	120 7			
		JIRAPA	153	41	26·8				
	EASTERN	AKWATIA	6	5	83·3				
		AKIM MANSO	6	6	100				
		ASIKASU	11	10	90·9				
		AKUSE	5	0	0·0	112·9	7 8	63	33·0
	ASHANTI	KUMASI	0	0	0	135·8	87	62	29·1
1977 — 1980	UPPER WEST	JIRAPA	136	34	25·0				
	EASTERN	MAASE	32	12	37·5				
		SOMANYA	207	44	21·3				
		AKUSE				83·7	77	61	32 7
	VOLTA	HOHOE	342	54	15·8	125·5			
		KPANDU				94·6	80	63	32·30
	BRONG AHAFO	WENCHI				93·6	85	59	30·36
		DORMAA AHENKRO	110	45	49·1	92·3	87	62	30·35
		HWIDIEM							
	ASHANTI	KUMASI	0	0	0	105·8	88	60	30·62
1983	NORTHERN	BOLE	92	52	56·5	63·5	53	35	37·5
		DAMANGO	30	17	56·6	72·0			
		GAMBAGA	76	46	60·6				
		TAMALE	7	5	71·4	62 · 4	42	22	35·8
	UPPER EAST	BAWKU	40	23	57·5				
		BOLGATANGA	13	13	100	76·8			
	UPPER WEST	WA	46	6	12·5	56·2			
		TUMU	7	2	28·5				
	BRONG AHAFO	KINTAMPO	12	12	100	82·8			
	ASHANTI	KUMASI	0	0	0	73·3	82	55	31·4
1987	ASHANTI	KUMASI	0	0	0	106·9	85	59	30·7
1963— 1983	ASHANTI	KUMASI	0	0	0	104.7	86	59	30·57
MEAN			1488*	461*	30·9	87·8	70	50	33·57

NB: THIS INFORMATION IS OBTAINED FROM THE FOLLOWING SOURCES ; AGADZI ET AL ; 1984 ; WHO EPID. REC. 1985 ; ADDY ET
* TOTALS OF YELLOW FEVER CASES AND DEATHS (1963 — 1983)

the A. (diceromyia) taylori furcifer group, together with A. neo-africanus, A. opok and A. furcifer abound in Ghana and have yielded Yellow Fever virus in most countries of West Africa (WHO, 1986). They may therefore play Yellow Fever vector role in Ghana. (WHO, 1986).

Only very fragmentary entomological data on Yellow fever vectors in Ghana have emerged from post-epidemic surveys (Mouchet, 1971). In most parts of the country, Aedes aegypti has obviously been found as domestic species. It was observed that in wild breeding sites in the forest zone in the South (Eastern Region) by Surtees (1958).

Data on other potential vectors are less informative. Edward (1941) gave a list of capture sites of Aedes stegomyia in certain parts of Ghana and Hamon (1970) collected data on the distribution and studies of potential Yellow fever vectors of certain arbovirus in West Africa. Mouchet (1971) gave a preliminary report on the distribution of potential vectors of Yellow fever in Ghana with particular reference to Aedes aegypti, A. luteocephalus, A. africanus, A. metallicus, A. vittatus and A. taylori-furcifer.

3.5.2 Man-vector Contact Rates and Larval Indices During Various Epidemics in the country

The first quantitative data was between 1916 and 1920 when Macfie and Ingram (1916-1920) reported finding Aedes aegypti species in over 80% of places where water had collected.

Ingram (1919) noted Aedes aegypti in 80% of the 40 places visited in Northern Ghana. Later, Burton et al. (1964) noted Aedes aegypti House index of less than 5% at Damongo.

Surveys carried out in the 1969 and 1970 epidemics gave larval Index of 8% for Navrongo and Bolgatanga and 5.8% for Paga in the North. At Asikuma in the South, the index exceeded 50% and there were up to 10 adult mosquitoes per house (Mouchet, 1971).

The following were the results obtained during the 1969-1970 epidemics in Ghana (Mouchet 1971) for man-vector contact rates and larval indices.

The Larval Index, an estimate of how receptive a population centre is to the transmission of Yellow Fever, is defined as the density of the breeding mosquito which may be assessed by determining the frequency of occurrence of Aedes (Stegomyia) aegypti (Linnaeus) in water-filled containers in and around houses (WHO, 1971).

The indices are categorized as follows:

House Index: The percentage of houses that are positive for larvae

Container Index: The percentage of all water-holding containers that are positive for larvae.

Breteau Index: The number of positive containers per 100 houses.

The Biting Rate: (Man-vector Contact Rate) is the number of female mosquitoes in contact with man per hour.

At Bawku: 10 Aedes aegypti per man-hour both inside yards and in the adjoining streets plus 1 Aedes of the furcifer-taylovi per man-hour.

At Bongo: in a region with scattered rural dwellings: 10 Aedes aegypti and 1 Aedes vittatus per man-hour.

In the town of Yendi: where all main roads are lined with trees in a district with few Aedes aegypti breeding places; 1.3 Aedes aegypti plus 1.3 Aedes luteocephalus plus Aedes gr. furcifer taylori per man-hour.

At Nakpanduri, in the village: 3 Aedes aegypti plus 0.7 Aedes vittatus plus 1.3 Aedes sp. furcifer-taylori.

At Pong Tamale, around the classrooms of the veterinary Assistants' School; 28 Aedes aegypti plus 0.25 Aedes vittatus plus 0.25 Aedes sp. furcifer-taylori per man-hour.

Navrongo, 12.5 Aedes aegypti plus 0.2 Aedes sp. furcifer-taylori per man-hour.

At Jirapa hospital and vicinity of the tyre dump: 32 Aedes aegypti per man-hour. 50 metres away from the breeding place; 6 Aedes aegypti per man-hour, House Index (HI) = 25, Container Index (CI) = 13, Breteau Index (BI) = 30.

At Bolgatanga hospital; 4 Aedes vittatus plus 1 Aedes aegypti per man-hour.

The larval indices during the epidemic periods were as follows:

Northern and Upper Regions (1969-70) House Index (HI) = 17

Container Index (CI) = 39.1 and

Breteaux Index (BI) = 93.8

In 1977-80, The Upper West Regions had the following records;

House Index (HI) = 11.3

Container Index (CI) = 7.8 and

Breteaux Index (BI) = 19.4

In 1983, the Northern sector had:

House Index (HI) = 74

Container Index (CI) = 31

Breteaux Index (BI) = 113

Eastern Region: (1969-70)

House Index (HI) = 50.0

Container Index (CI) = 23.4 and

Breteaux Index (BI) = 84.2

Eastern Region(1977-80)

House Index (HI) = 36.4

Container Index (CI) = 38.0 and

Breteaux Index (BI) = 96.1

Volta Region (1977-80)

House Index (HI) = 45.2

Container Index (CI) = 4.0 and

Breteaux Index (BI) = 9.0

3.5.3 Preventive and Control Measures Adopted in Ghana

Before the Towns Ordinance (Anon, 1951) in Ghana (Cap. 86 of 4:11:1892) which empowered the Health Minister to regulate the erection of buildings in towns in the interest of Public Health, the inhabitants in many villages used to control mosquitoes by destroying drums, jars or pots or they emptied out any remaining water and did not rely on Health service instructions.

Later, a National Legislation establishing mosquito control was enacted as the Mosquito Ordinance (Anon, 1954) Cap 75 of 13:4:1911 and it involved anti-mosquito measures by Sanitary Inspection such as the destruction of mosquito larvae and the screening of water receptacles from mosquito larvae.

After the Mosquito Control Ordinance, the control measures involved:

1. Clearing of vegetation at the edges of streams
2. Filling of burrow pits.
3. Covering domestic water containers in and around houses.
4. Screening houses with mosquito netting and the use of mosquito nets.

Again, there was the use of insect repellants indoors. Furthermore, Health Inspectors in charge of a District, normally

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paid periodic visits to nearby villages to check mosquito breeding in streams, ponds and domestic water containers, and putting under cover large dump of worn-out tyres and covering water tanks and reservoirs.

Chinery (1969) surveyed mosquito breeding in Accra with suggestions for future control considerations. More recently, there was community involvement in mosquito control programmes by organizing durbars and again, the CDRs (Committees for Defence of the Revolution) and Health Inspectors have taken measures like filling of burrow pits, making canals of street drains, stagnant waters and nearby pools of water.

Other preventive and control measures were mainly mass immunization programmes and spraying of mosquito larval and adults, organized by Ministry of Health, in collaboration with the WHO. The insecticides commonly used as complementary control measures were DDT (Dichloro-diphenyltrichloroethane) and BHC (Hexachlorocychlorohexane), which are readily available and have been used for a long time but the development of resistance to these 2 products, together with their costs involved has limited their use. Reslin 15s (15-benzyl-3-fury (methyl-(+)-trans Chrysanthemate and the (+)-trans-chrysanthemic acid of (+)-allethrolen synerginized by piperonyl butoxide) and Aqua Reslin)3-phenoxybenzyl (-) cis, trans 2,2 dimethyl-3-(2,2-dichlorovinyl) cyclopropane-1- carboxylate) are commonly used (in concentration of 1:6.5 Kerosene and 1:9 water respectively but Reslin 15s is very costly (WHO, 1974; Service, 1979).

At present, the larvaecide of choice is Abate (0,0,0'0'-tetramethyl 0,0' thiodi-p-phenelene phosphorothionate and Vapona 2,2-dichloro vinyl 0,0-dimethyl phosphate). Abate is extremely

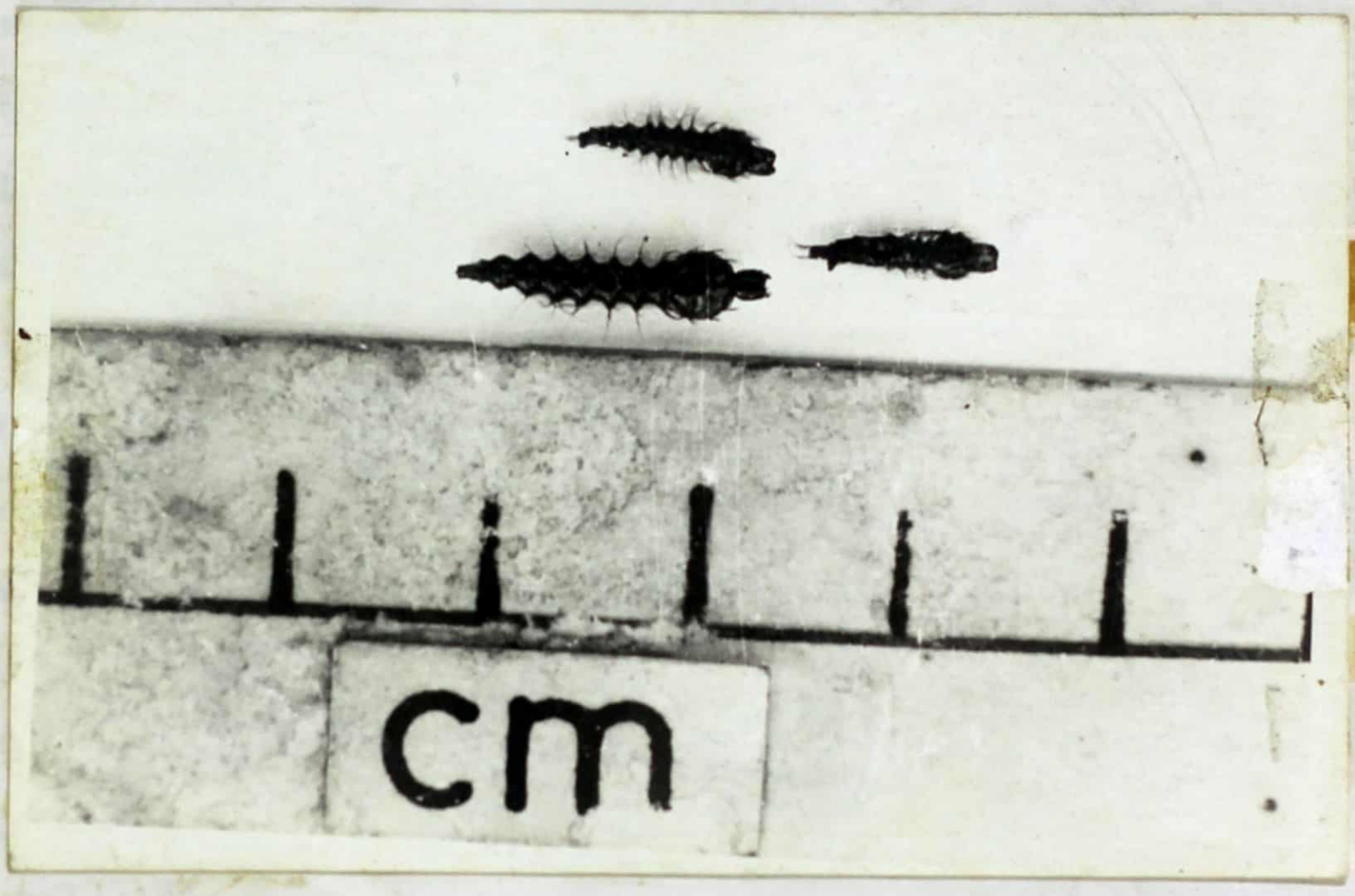

PLATE 1: 2ND, 3RD AND 4TH INSTAR LARVAE OF TOXORHYNCHITES BREVIPALPIS THEOBALD.

Upper and lower caudal setae with 3-6 and 3-4 simple branches respectively; lateral seta placed almost on the posterior margin, single very stout and closely plumose. Ventral brush composed of 8 or 9 pairs of tufts, each of which consists of a strong coarsely plumose seta. "Gills" subequal, very short and rounded.

2.6.1 Historical Review of Toxorhynchites

The use of the giant mosquito Toxorhynchites for biological control was started in 1934 when Paine (1934) introduced Toxorhynchites splendens from Java to Fiji for a control of Aedes scutellaris, the primary vector of filariasis in that country. Later, Bonnet and Hu (1951) introduced Tx. brevipalpis from South Africa for the control of Aedes albopictus in Hawaii. Paterson (1956) also introduced Tx. brevipalpis for the control of Aedes pseudoscatellaris in Samoa.

At least 57 species of Toxorhynchites are known to exist (Trpis, 1970). These species are widely distributed in tropical and subtropical areas. This group of mosquitoes is wild and species breed in tree holes, bamboo stumps and discarded tyres (Trpis, 1970).

Although Toxorhynchites have been studied for more than the past 20 years, yet the biology and Taxonomy of these species have not been studied in greater depths as has been the case of other musquito species. However, there is progress in the biological studies of some Toxorhynchite species in the laboratory. For example, Yasuno and Tonn (1970) investigated the distribution and habitats of Tx. splendens in South-East Asia. During the study, Tx. spendens was noted to be a possible mortality factor in certain containers such as water jars but not in other containers.

Earlier however, Paiva (1910) noted that Tx. splendens larvae were predators of a number of mosquito larvae in India. Also Jenkins (1964); and Laird (1947) observed the predatory capacity of the genus Tx. splendens and also noted their feeding capacities and their ability to resist starvation.

Burton and Rudnick (1973) also made biological studies of Tx. spendens, Tx. leicesteri, Tx. quasiferox and Tx. metallicus in South-East Asia to find out Toxorhynchites colony maintenance.

Sato and Takahashi (1974) discovered Tx. towadensis in Japan for the first time, and Fock and Hall (1977) discovered Tx. rutilus in the United States of America.

Fock and Boston (1979) developed a quantified mass-rearing technique for Toxorhynchite rutilus (coquillet) which enables one person to produce several thousand adults every two weeks.

Fock et al. (1978) successfully reared Tx. rutilus rutilus on a non-living diet of a commercially available food for tropical fish, and confirmed the significance of Tx. rutilus rutilus as a biological control agent for container - breeding mosquitoes.

Biological and Ecological studies to prove the predatory potential of Toxorhynchites species were also studied by Chan 1968; Trpis and Gerberg, 1970; Furumizo et al. 1977.

4.0 DESCRIPTION OF THE STUDY AREA

Kumasi, Akropong and Ejisu were selected as the study areas because of ecological variations, the urban nature of Kumasi and the proximity of the two rural towns to the University campus. However, the bulk of the work in the Kumasi area was concentrated on the University campus and Anloga, a suburb .

4.1 The Kumasi Area

The Kumasi area is on a low plateau of about 300 metres above sea level. The plateau is dissected by a number of streams, for example Subin river, Denyame river, Kwadaso river, Aboabo river and Sisai river so that on the plateau are ridges which form the main built-up areas. The immediate banks of the streams are marshy and some have been drained and developed. In Ashanti region however, the main rivers are Afram and the Ofin river which is the boundary between Central Region and Ashanti, Lake Bosumtwi is in South-East of Kumasi and the Volta Lake extends into its eastern part. Also the Pra river is the boundary between Ashanti and Eastern Region.

There is the Ashanti section of the Koforidua-Mampong escarpment, and also in the southern parts are some highlands (Boateng, 1970). The land slopes from about 300 metres in the north to 150 metres in the south. There are several hills and ranges which stand above the general level in some places. Some of these hills rise between 500 and 850 metres above sea level. Two of the most prominent of these ranges are the Adansi Mountains, extending South-Westwards from the Lake Bosumtwi and the range between Nsuta

and Bibiani, 48 kilometres west of Kumasi. The North-east to South-West trend which is repeated by almost all the other ranges in the region, appears to correspond to the direction of folding in ancient geological times (Boateng, 1970). The present ranges seem to be largely the result of prolonged erosion working on rocks of varying hardness.

Kumasi is located in the centre of the southern part of Ghana and because of its location several roads converge on it from Accra, Atebubu, Sunyani, Bibiani, Dunkwa and Cape Coast. It is also the converging point of the 2 main railway lines in Ghana, namely the Western line from the Sekondi-Takoradi and the Eastern line from Accra.

The climate is semi-equatorial type. Rainfall is about 145 centimetres (1450 millimetres) per annum and provides ideal conditions for deciduous forest. Rainfall is not evenly distributed. There are some months with heavy rainfall and others little. The 2 rainfall seasons are: March to July and September to November. The seasons are separated by relatively dry periods. The long dry period from December to February and the short dry period of July and August. Rainfall is variable annually, seasonally and monthly. Rainfall can be torrential and especially in the evening. The weather is generally cloudy in the rainy season and fine in the dry seasons and in the mornings.

The maximum average annual temperature is 25.5°C and the minimum average annual temperature is 21°C. The highest temperature is experienced between February and March when the average is about 32.2°C. The minimum temperature is mainly in December and January

when it is 19.4°C and 20.0°C respectively and in August when it is about 20.5°C.

Kumasi experiences the harmattan from December to early February when the weather is dry and hazy. It is also cool in the night.

Vegetation is semi-deciduous type with some of the trees shedding their leaves at different times so that the forest appears evergreen throughout the whole year. There is very little sign of the original vegetation in the Kumasi area, and much of it having given way to farms. Timber exploitation and occasional bush fires have also resulted in the disappearance of the original vegetation. What appears as vegetation in the area is partly man-made and partly secondary, which is mainly a low type of secondary bush with isolated valuable timber. However, in other parts of the region, there are forest reserves. Some of the popular trees in the area are Ceiba pentadra Linn. (Silk cotton tree) Elaeis guineensis Jacq (Oil palm), timbers such as Chlorophora excelsa A. Chev (Odum), Brachystegia eurycoma Harms (which reach heights of about 23 metres) and Khaya grandifoliola C. DC (Mahogany) Irvine (1961). Others of similar heights are Blighia sapida Konig Spathodea campanulata P. Beav. Bombax buonopozense P. Beav. is about 40 ft. Tectona grandis Linn (Teak) and Gmelina arborea Roxb (Gmelina) are normally planted in Taungya farms for afforestation.

Apart from Ejura which is savannah area, the vegetation is the same throughout the region.

Kumasi is the main settlement area with a population of about 500,000. Around it are villages of various sizes. There are close cultural and functional relationship between Kumasi and the surrounding

villages. There is a lot of movement in Kumasi and between Kumasi and the surrounding villages and the other parts of the country. Migration has resulted in the development of special areas in Kumasi. Some of these areas like Anloga, are largely ethnic.

Kumasi being a city, performs several urban functions such as commerce, trade, transport, manufacturing and social services including health and education. In addition to the residential areas mentioned above, there are Ashanti New Town, Fante New Town, Asafo, Bantama and Suame.

In the suburbs of Kumasi which are physically not part of the main built-up, live mainly Ashantis. Kumasi is surrounded by a number of large towns for example Ejisu, Juabeng, Obuasi, Asante Mampong, Kumawu, Konongo, Agogo, Ejura and Tepa. Obuasi is the largest of these towns with a population of about 40,000. The population of Obuasi is more heterogenous than all other towns.

Occupation in the other towns are varied. There is mining in Konongo and Obuasi. Other occupation are mainly service and commerce. Many of the people are also in farming. There are a few rural industries.

Food growing is important in the Ashanti region. The large market provided by Kumasi and the mining towns of Obuasi and Konongo has helped food farming in the area. The commonest crops are Colocasia esculantum Vigne (Cocoyam); Manihot utilissima Linn. M. mesculenta (Cassava) Linn. Musa paradisica Linn. (Banana). Musa sapientum Linn. (Plantain) Zea mays Linn. (Maize) and various forest variety of Dioscora cayenensis Linn and D. alata Linn (Yams).

Gallus domestica (Poultry) and livestock such as Ovis spp (sheep); Capra spp. (goats) are reared for local consumption. Sus spp. (pigs) and Bos indicus and B. taulus (Cattle) are reared rather sparsely. Fishing is also done on a little scale in Lake Bosumtwi and the rivers. The main industrial crops are Cola nitida Linn. (Cola); Coffea arabica Linn. C. robusta Linn (Coffee) and Theobroma cacao Linn. (Cocoa) grown throughout the region.

4.2 The University Campus (U.S.T.)

The campus is situated on a 17.92 square kilometre piece of undulating land about 6.4 kilometres from Kumasi along Accra-Kumasi Road. The campus has modern buildings interspersed with lawns and tropical flora such as Poincinia regia Boj (Flambouyant) Peltophorum pterocarpum Backer (Rust tree) Largestroema speciosa Linn. (Queen flower), Roystonea regia (Royal palm); Tectona grandis Linn. (Teak) Magnifera indica Linn (Mango). In addition to this is a 10 acre Botanical garden which gives the area the semblance of a forest (Plate 2). Examples of such trees are: Chlorophora excelsa A. Shev. (Odum) Bombax buonopozense P. Beav; Piptadeniastrum africanum Hook Musanga cecropioides R. Br. and Khaya grandifoliola. C DC

The dominant trees that provide tree holes on the campus are Poincinia regia Boj (Flambouyant) (Plate 3). Pithecellobium saman Benth (Rain tree) also provide a few tree holes. Other common trees scattered on the campus are: Mechelia champaca L. (Champaca): Termindia catapa Linn (Indian almond) Magnifera indica Linn. (Mango); Elaeis guineensis Jacq (Oil palm); Psidium guajava Linn and Persea gratissima Gaertn. (Avocado pear).

PLATE 2: A TYPICAL FOREST IN ASHANTI REGION WHICH PROVIDE BREEDING GROUNDS FOR AEDES MOSQUITOES AND TOXORHYNCHITES

PLATE 3: TREES ILLUSTRATING THE GENERAL POSITIONS OF TREE HOLES AT THE U.S.T. CAMPUS

The University has residential facilities for students, teaching staff and their families. The population is about 7,000, rather heterogenous with free mixing of the senior staff, office workers, students, labourers and inhabitants of nearby villages.

The banks of several streams flowing across the compound have been developed into irrigated farmlands, where vegetables such as lettuce, cabbage and melons are cultivated.

4.3 Anloga

A suburb of Kumasi is found 3.2 kilometres South-East of Kumasi. The area is about 0.5 km^2 and an elevation of 259.00-274.30 metres above sea level. Most of the trees have been destroyed in this area. Breeding grounds for mosquitoes are simply water receptacles, lorry tyres, drains and abandoned fish ponds. The soil is sandy clay in texture.

The majority of the people are engaged in the wood industry as sawnmillers, wood hawkers and carpenters. The suburb could be described as mainly a slum area.

4.4 Ejisu

A town of about 18 kilometres East of Kumasi. The area is 1.28 km^2 and the elevation is 274.3-289.50 metres above sea level. The vegetation is semi-deciduous forest with patches of derived savannah. The trees are scattered and provide few tree-holes. In the various homes, there were many water receptacles which provided breeding grounds for mosquitoes. The soil is well drained over granite. The valley bottoms are clayey.

The people are predominantly farmers, growing such cash crops as cocoa, and food crops like cassava, plantain and cocoyams.

4.5 Akropong

A town of about 16 kilometres North-West of Kumasi. The area is about 0.64 km^2 and the elevation is 213-228.6 metres above sea level. Vegetation immediately around the town is derived savannah with elephant grass, Panicum maximum Jacq and spear grass P. deflexum Schum. There are few scattered trees especially flambouyant trees Poincinia regia Boj and water receptacles and drains in the town also provide breeding grounds for mosquitoes. The valley bottoms are clayey and acidic.

The bulk of the workers are engaged in Poultry industry. There is a heavy concentration of Poultry farms at Akropong and the biggest Poultry Enterprise in Ghana, namely Darko Farms Limited, is situated at Akropong.

5.0 MATERIALS AND METHODS

5.1 Identification of the Aedes Mosquitoes

Both adults and larvae of the Aedes mosquitoes were identified according to Edwards (1941), Hopkins (1952), Smart et al (1956) and WHO (1972).

Confirmatory tests for the species were made by identifying the second filial generation of the mosquitoes (both larvae and adults).

Other mosquitoes collected during the study were identified according to Hopkins (1952), and WHO (1972).

5.2 Climate of Kumasi Including the University Campus and Anloga

The mean climatological data for the past 10 years (1977-1986) in the Kumasi area and also those of the study period (1987/88) were obtained from the Meteorological Services Department.

5.3 Determination of Relative Densities of Mosquitoes in the Study Areas

Depending on the type of breeding ground, a Siphon (Appendix Fig. 1) a Pooter (aspirator) (Appendix Fig. 2), a ladle (Appendix Fig. 3) or a sweep net (Appendix Fig. 4) was used to collect some water sample to fill a 120 millilitre specimen bottle.

Specimens were taken from a wide range of receptacles such as tree holes, lorry tyres, water tanks, household water containers, irrigation canals, crab-holes, rock pools, ground pools and ponds.

Once a week, 20 specimens were randomly collected from various localities within the University campus. At least one specimen was taken from any of the following places: the Botanical Garden, the irrigated farmland, Halls of Residence, the Teaching

area, (Departments), Senior Staff Residence, Junior Staff Residence, an Orange Orchard, the Medical School premises and the Swampy areas. Another 20 specimens each were collected from Anloga, Akropong and Ejisu.

The specimen bottles were sent to the laboratory for analysis.

5.4 Mosquito Larval Indices

Mosquito larval indices at Akropong, Ejisu, Anloga and the Junior Staff Quarters of the University were assessed.

The assessment was performed on up to 50 houses and the surrounding premises associated with each house, and all containers with water were examined. The results obtained were categorized in terms of one, two or three of the following indices (WHO, 1971).

5.4.1 House Index

Expressed as percentage of houses that are positive for larvae.

5.4.2 Container Index

Expressed as percentage of all water-holding containers that are positive for larvae.

5.4.3 Breteau Index

Expressed as number of positive containers per 100 houses.

In establishing the indices, the term "house" was taken to include all the buildings occupied by one family. Only those containers in which there was water likely to harbour *Aedes* larvae were considered. Thus, of the empty jars and drums, only those in a position to capture rain-water during the rainy season were recorded.

All containers found in the compound whether inside or outside dwellings were considered to belong to the house (Mouchet, 1971; unpublished). In both cases, these larval breeding places are in close contact with man, and at dusk (active period for Aedes aegypti) the inhabitants generally congregate in their yards.

Dumps of old tyres and scrap iron were also examined as well as installations around new buildings and also around warehouses and vehicle maintenance yards.

5.5 Man-Vector Contact Rate

The vector biting rate (index) is the ratio of the Aedes female caught biting to the period of exposure of human bait, multiplied by the number of people serving as a bait. In the case of human bait, 3 people were normally expressed for 2 hours i.e. 6 man-hours.

The biting rate was taken as a team of 3 men exposed for a period of time, collecting from themselves and from each other. All mosquitoes landing on the men, and presumed to bite were collected into vials, counted and identified at the end of the period.

5.6 Biting Cycle of Aedes species

Five human baits were used for night catches. The mosquitoes were collected off the baits after every hour into different containers. This was carried out throughout the night and the mosquitoes sexed and counted. This experiment was performed fortnightly throughout the year at Ejisu, U.S.T., Anloga and Akropong.

5.7 Life-span of Larval Instars of Toxorhynchites

A number of Toxorhynchites larvae were collected from various habitats and were individually separated into different containers and the dates recorded. The second larval instars of Aedes aegypti were offered as prey to Toxorhynchites larvae.

Daily observations were carried out on the development of larvae and pupae in order to record the span of each developmental period.

The width of head capsules of each larval instar was measured by the use of a micrometer fixed on a microscope to determine growth of the larvae.

Pupae were transferred to a mosquito cage of 30 x 30 x 30 centimetre dimension for the adult to emerge. Cotton pads soaked with sucrose solution were provided for the adults (as nectar source). Thorax and wings of newly emerged adults were marked with red colour paint to determine life-span.

Later, observation and records were made on the eggs that were laid on wet filter papers in petri dishes placed in the cages.

5.8 Starvation of Toxorhynchites

The first instar Toxorhynchites larvae were divided into 5 groups. Ten (10) larvae of each group were treated as follows:

Group 1: The 10 first instar larvae were kept in the breeding bottle without any prey, and records of mortality were taken.

Group 2: The 10 Toxorhynchites were provided with a daily supply of 100 Aedes mosquito larvae. Any Toxorhynchites which moulted to 2nd instar, was transferred into another container which had no Aedes as food. The Toxorhynchites were observed till they were all dead.

Meanwhile, fresh supplies of Aedes were given to the mosquitoes which had not yet moulted to second instar.

Group 3: The Toxorhynchites were fed daily with 100 Aedes mosquito larvae as in Group 2 until the Toxorhynchites reached the 3rd instar stage when feeding was stopped. Mortality of

Toxorhynchites was recorded.

Group 4: Starvation of Toxorhynchites began after feeding them as before till the larvae moulted to the 4th instar when feeding was stopped. Mortality among the 4th instar insects were recorded.

Group 5: The 10 first instar larvae were fed daily with 100 Aedes mosquito larvae throughout the larval stages until they moulted into the pupal stage. Any mortality was noted.

The experiment was replicated 5 times.

5.9 Feeding Capacity of Toxorhynchites on Aedes aegypti mosquitoes

Ten (10) first instar larvae of Toxorhynchites were placed in specimen bottles and a known number of second instar Aedes aegypti provided to the larvae. Everyday, number of live prey larvae (Aedes aegypti) were counted in order to determine the number consumed or killed. The undevoured larvae were taken out and replaced by fresh ones. Observations were carried out until pupation of Toxorhynchites and the total number of prey eaten by each inster of Toxorhynchites was calculated. The experiment was replicated 4 times.

5.10 Feeding Preference of Toxorhynchites on Different Species of Mosquitoes

Experiment on the feeding preference of Toxorhynchites was made on the second instar larvae of Aedes aegypti, Culex decens and Anopheles gambiae mosquitoes, as preys.

Ten (10) fourth-instar Toxorhynchites larvae were placed in 10 separate bottles of 120 millilitre capacity each. Exactly

20 larvae of each of the 3 mosquito species (as preys) were added to the bottles containing Toxorhynchites and left for 24 hours.

At the end of the 24 hour period, the numbers and types of mosquito larvae eaten or killed were counted. The killed or eaten larvae were constantly replaced by fresh ones and the experiment which was replicated 10 times was continued for 21 days.

5.11 Distribution of Toxorhynchites in the Study Area

Records of Toxorhynchites encountered on the field both on the U.S.T. campus and other Districts were recorded; but intensive field survey of Toxorhynchites larvae was made on the U.S.T. Campus in April, May and June 1987.

The temperature and pH of the stagnant water were determined by using thermometers, and pH meters respectively.

The distribution and predatory activities of the minor predators such as Culex (Lutzia) tigripes, Notonecta, Nepa sp. (Water scorpion), Hydrometra (Water stick), Belostoma (giant water bug) and Lispa (anthomyid fly), were observed but not studied.

5.12 Sampling of Mosquito and Toxorhynchites Populations in Regions Bordering Ashanti

Sampling of mosquito and Toxorhynchites populations in tree-holes was made in June/July 1987 and June/July, 1988. The following Regional capitals were selected and at least 100 tree-holes were sampled from shade trees growing in each of the Regional capitals during the rainy season; Accra, Koforidua, Ho, Cape Coast, Takoradi-Sekondi and Sunyani.

In the cocoa-growing areas such as Kade, Tafo, Koforidua (Eastern Region), Goaso, Sunyani (Brong-Ahafo Region), cocoa-pod husks in some cocoa farms were also examined in addition to the tree-holes during the period June/July, 1987, June/July, 1988, October, 1987, and October, 1988.

No sampling was carried out in the Northern and Upper Regions.

5.13 Analysis of Data

The data were analysed statistically using analysis of variance, X^2 (Chi-squared) and the F-test of significance according to Parker, (1975) and Bishop (1980).

The least significance difference test (L.S.D.) was further used to determine possible significant differences among means.

6.0 RESULTS

6.1 Identification of Aedes Mosquitoes

The mosquito species identified during the research in the study areas were as follows: Aedes (Stegomyia) aegypti Linnaeus (Appendix Fig. 5); Aedes (Stegomyia) africanus Theobald (Appendix Fig. 6); Aedes (Stegomyia) luteocephalus Newstead (Appendix Fig 7) Aedes (Stegomyia) vittatus Bigot (Appendix Fig. 8).

The other mosquitoes identified were as follows: Culex (Culex) decens Theobald. Culex (Colex) thalassius Theobald. Culex (Lutzia) tigripes Grandpre, Anopheles gambiae S.1 and Toxorhynchites brevipalpis Theobald (Appendix 9).

6.2 Climate of Kumasi Including the University Campus and Anloga

The mean climatological data for the past 10 years (1977-1986) and also that of 1987/88 are shown in Fig. 2.

The highest mean rainfall for the past 10 years was 200.8 millimetres and that for 1987/88 was 245.8 millimetres in the months of June. The minimum rainfall is always in January and for the past 10 years the mean was 6.1mm.

The maximum and minimum temperature during the rainy season is often lower than those of the dry season, but the percentage relative humidity at 0600 Hours GMT and 1500 Hours GMT is higher in the rainy season than in the dry season. Sunshine has generally longer period in the dry seasons than in the rainy season.

The mean climatological records for the past 10 years (1977-1986) as compared with that of 1987/88 are respectively as follows:

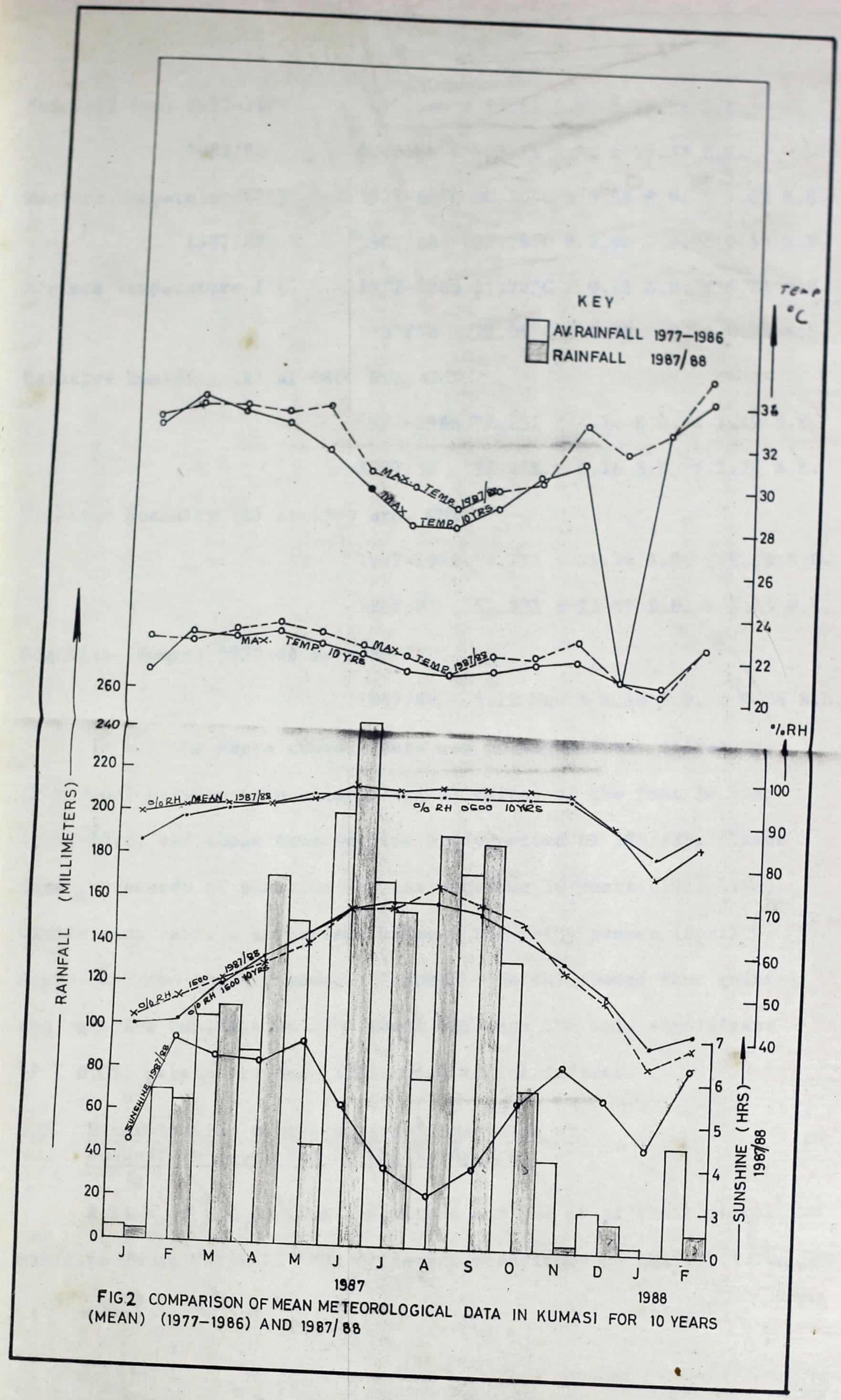

FIG 2 COMPARISON OF MEAN METEOROLOGICAL DATA IN KUMASI FOR 10 YEARS (MEAN) (1977–1986) AND 1987/88

Rainfall (mm) 1977-1986 103.13mm ± 63.61 S.D. ± 18.36 S.E

1987/88 86.56mm ± 103.11 S.D. ± 29.77 S.E.

Maximum Temperature(°C) 1977-1986 30.10°C ± 3.58 S.D. ± 1.03 S.E.

1987/88 1987/88 31.79°C ± 1.90 S.D. ± 0.55 S.E.

Minimum Temperature (°C) 1977-1986 21.72°C ± 0.75 S.D. ± 0.21 S.E.

1987/88 22.09°C ± 0.88 S.D. ± 0.25 S.E.

Relative Humidity (%) at 0600 Hrs. GMT

1977-1986 92.25% ± 4.14 S.D. ± 1.19 S.E.

1987/88 92.41% ± 6.16 S.D. ± 1.78 S.E.

Relative Humidity (%) at 1500 Hrs. GMT

1977-1986 57.75% ± 11.18 S.D. ± 3.19 S.E.

1987/88 57.33% ± 11.99 S.D. ± 3.75 S.E.

Sunshine (Hours) 1977-86 No records

1987/88 5.23 Hrs ± 1.18 S.D. ± 0.34 S.E.

In all the above cases, there was no significant difference ($P > 0.05$) between mean climatological values of the past 10 years (1977-1986) and those covering the study period of 1987/88. There were no records of sunshine for the previous 10 years (1977-1986). Within each year, a comparison between the rainy season (April - September) and the dry season (October - March) showed that rainfall and relative humidity at 1500 Hours GMT were the only significant ($P < 0.05$) parameters that influenced vector indices.

6.3 Determination of the Relative Densities of Mosquitoes Colelcted in the Study Area

A list of the various mosquitoes and the pH of their respective habitats is in Table 2. The different mosquitoes on the U.S.T. Campus

UNIVERSITY OF SCIENCE AND TECHNOLOGY

MAP OF THE COMPOUND

LEGEND

AEDES AFRICANUS	● = 100
AEDES LUTEOCEPHALUS	◪ = 10
AEDES VITTATUS	⊕ = 100
AEDES AEGYPTI	● = 1000
TOXORHYNCHITES	⊠ = 100
OTHER MOSQUITOES	⊡ = 100

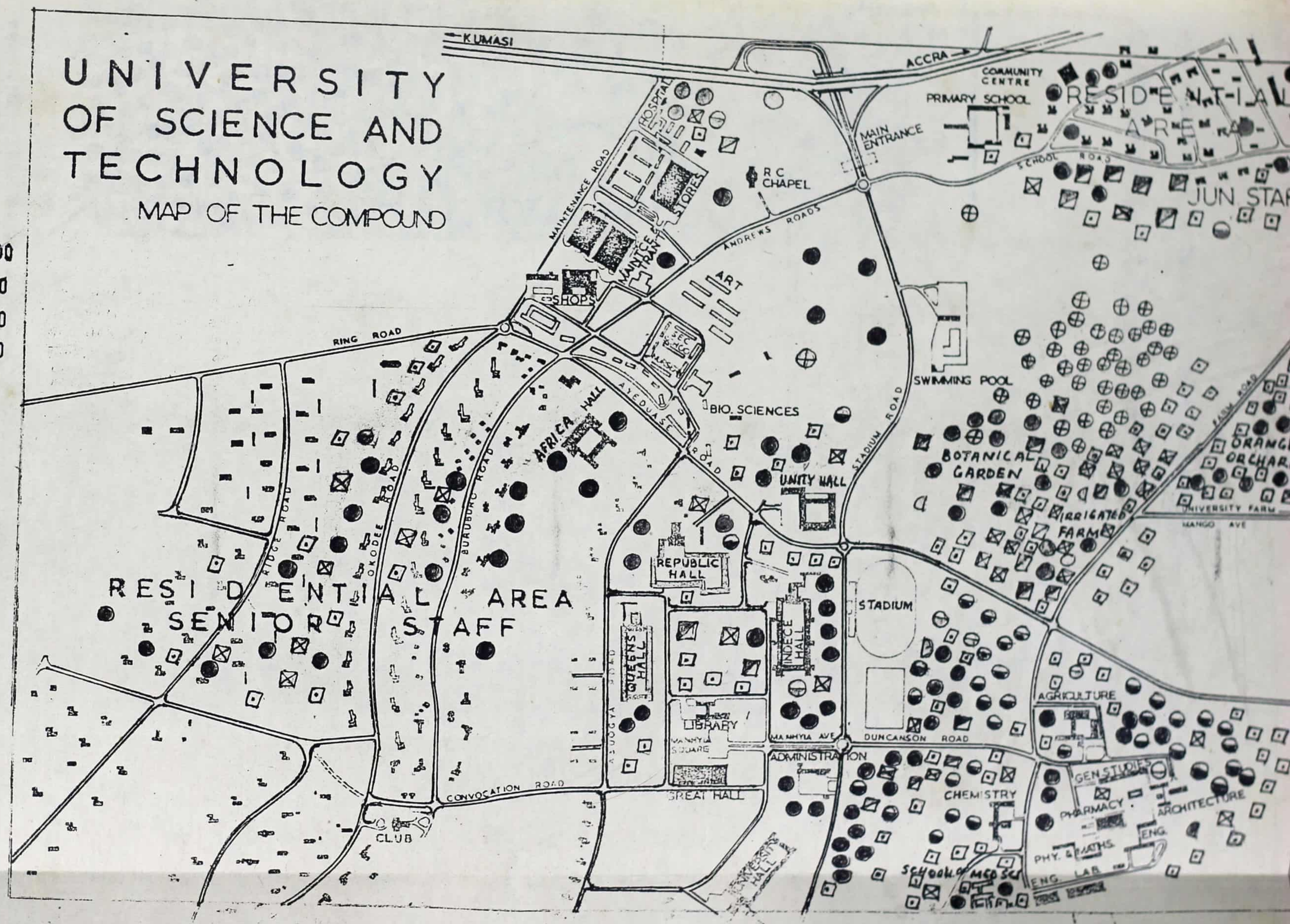

FIG 3 DISTRIBUTION OF THE VARIOUS SPECIES OF MOSQUITO ON UST COMPOUND THROUGHOUT THE YEAR

are also found in Table 3. The distribution of the various species of mosquitoes at U.S.T. is represented in Fig. 3. The comparative

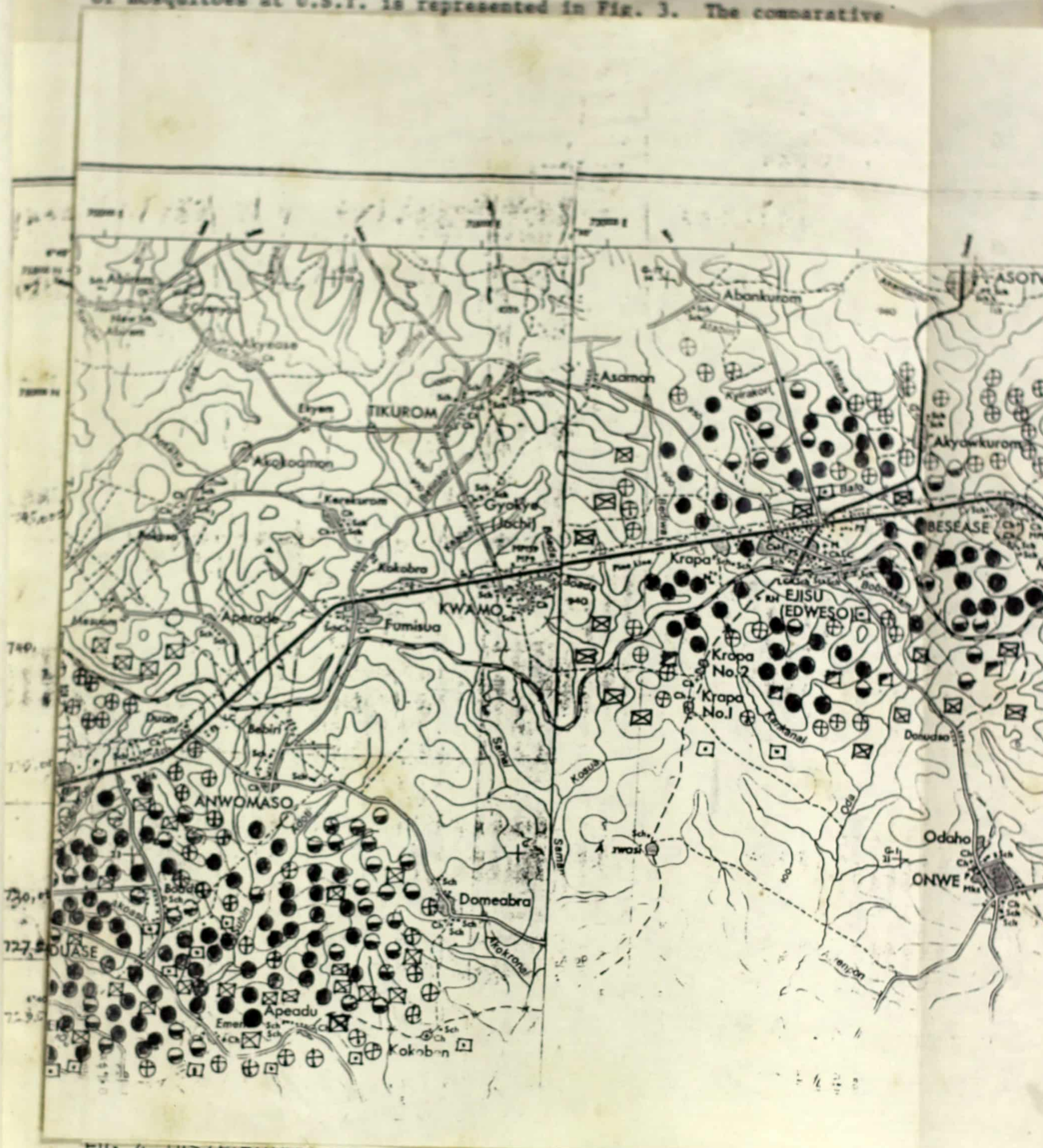

FIG 4 DISTRIBUTION OF THE [illegible]

[illegible] Ae vittatus pH 8-9, Toxorhynchites pH 6-10. Other mosquitoes (mainly Culex) pH 6-8. Aedes aegypti appears to prefer acidic to neutral media while Ae africanus and Ae luteocephalus prefer neutral to

are also found in Table 3. The distribution of the various species of mosquitoes at U.S.T. is represented in Fig. 3. The comparative distribution at Ejisu, U.S.T., Anloga and Akropong is in Fig. 4.

Aedes aegypti is the predominant (81%) and widely distributed mosquitoes in the 3 districts. This is followed by Aedes vittatus (3.3%) and Toxorhynchites (3.1%). The bulk of other mosquitoes (apart from Aedes and Toxorhynchites in all the districts add up to 9.5%.

Aedes vittatus is mainly found in rock pools and is mainly found at U.S.T. Campus. It persists throughout the year just as Aedes aegypti and Toxorhynchites brevipalpis.

The highest density of mosquitoes occurred between June and September when about 60.3% of the total insects were collected. With an average number of 16.5% the month of June, was the period of the greatest number of insects, while January with a percentage of 0.2% recorded the least number of insects.

At the U.S.T. Campus, Aedes aegypti was found to be the most dominant species throughout the year and is about 79.5% of the yearly total. The least Ae. luteocephalus, is 0.2%, Ae africanus is 3.8%, Ae vittatus is 3.2%, Toxorhynchites is 2.3%. Other mosquitoes (mainly Culex) is 11%.

Aedes aegypti, A. vittatus and Toxorhynchites are the most widely distributed and occur almost throughout the year.

The respective pH ranges of the various mosquito habitats were as follows: Aedes aegypti pH 6-7, Ae africanus pH 7-8, Ae luteocephalus pH 7-8, [redacted] Ae vittatus pH 8-9, Toxorhynchites pH 6-10. Other mosquitoes (mainly Culex) pH 6-8. Aedes aegypti appears to prefer acidic to neutral media while Ae africanus and Ae luteocephalus prefer neutral to

TABLE 2 COMPARISON OF MONTHLY MOSQUITO LARVAL FREQUENCIES IN FOUR [illegible] SHOWING THE DENSITIES OF THE VARIOUS MOSQUITO SPECIES AND [illegible] SPECIES [illegible] THE PH OF THEIR RESPECTIVE HABI[illegible]

MONTH	MOSQUITO SPECIES	ANLOGA		EJISU		UST		AKROPONG		pH	TOTALS		% PRESENCE IN BREEDING
		TOTAL	%	TOTAL	%	TOTAL	%	TOTAL	%			% SPECIES	
FEBRUARY (1971)	Ae aegypti	78	55.3	28	31.1	177	81.5	36	50	6-7	317	61	1.7
	Ae africanus	21	14.9	18	20	5	2.3	3	4.2	7-8	47	9	
	Ae luteocephalus									7-8			
	Ae vittatus	8	5.7	21	23.3	6	2.7			8-9	35	7	
	Toxorhynchites	12	8.5	8	8.9	4	2	21	29.2	6-10	45	9	
	Other anopheines	22	15.6	15	16.7	25	11.5	12	16.6	6-8	74	14	
	TOTALS	141	100	90	100	217	100	72	100		520		
MARCH	Ae aegypti	623	89.8	850	81.3	1236	84.4	438	90.8	6-7	3147	88	11.8
	Ae africanus	10	1.4	7	0.7	23	1.5			7-8	40	1	
	Ae luteocephalus			13	1.2					7-8	13	0.4	
	Ae vittatus			120	11.5	7	0.5			8-9	127	3	
	Toxorhynchites	36	5.2	25	2.4	33	2.3	18	3.7	6-10	112	3	
	Other mosq.	25	3.6	31	2.9	166	11.3	26	5.4	6-8	248	7	
	TOTALS	694	100	1046	100	1465	100	482	100		3575		
APRIL	Ae aegypti	208	66	309	73.9	997	76	150	72.1	6-7	1664	74	7.4
	Ae africanus	12	3.8	23	5.5	57	4.3	14	6.7	7-8	106	4.7	
	Ae luteocephalus					9	0.6			7-8	9	0.4	
	Ae vittatus			55	13.2	9	0.6			8-9	64	2.8	
	Toxorhynchites	18	5.7	31	7.4	43	3.3	15	7.2	6-10	107	4.7	
	Other mosq.	77	24.4			188	14.4	29	13.9	6-8	294	13	
	TOTALS	315	100	418	100	1303	100	208	100		2244		
MAY	Ae aegypti	404	86.7	530	88	1161	86	293	87.2	6-7	2388	86	9.1
	Ae africanus			17	2.8	28	2.1			7-8	45	2	
	Ae luteocephalus									7-8			
	Ae vittatus			21	3.5	23	1.7			8-9	44	1.6	
	Toxorhynchites	27	5.8	19	3.2	30	2.2	12	3.6	6-10	88	3.2	
	Other mosq.	35	7.5	15	2.5	108	8	31	9.2	6-8	189	6.8	
	TOTALS	466	100	602	100	1350	100	336	100		2754		
JUNE	Ae aegypti	913	86.9	1045	91.8	1828	83.8	609	92.8	6-7	4395	87	16.5
	Ae africanus	15	1.4	36	3.2	61	2.8			7-8	112	2.2	
	Ae luteocephalus					3	0.1	9	1.4	7-8	12	0.2	
	Ae vittatus					57	2.8			8-9	57	1.1	
	Toxorhynchites	51	4.9	36	3.2	48	2.2	25	3.8	6-10	160	3.2	
	Other mosq.	71	6.8	21	1.8	183	8.4	13	2	6-8	188	5.7	
	TOTALS	1050	100	1138	100	2180	100	656	100		5024		
JULY	Ae aegypti	609	88	893	85	2055	79.3	532	84.8	6-7	4089	82.4	16.3
	Ae africanus	8	1.1	15	1.4	149	5.7	12	1.9	7-8	184	3.7	
	Ae luteocephalus					4	0.2	3	0.5	7-8	7	0.1	
	Ae vittatus			61	5.8	171	6.6	28	4.5	8-9	260	5.2	
	Toxorhynchites	24	3.5	13	1.2	26	1.0	21	3.3	6-10	84	1.7	
	Other mosq.	51	7.4	68	6.5	185	7.2	31	4.9	6-8	335	6.8	
	TOTALS	692	100	1050	100	2590	100	627	100		4959		
AUGUST	Ae aegypti	728	78.7	850	78.9	1153	71.6	620	79.9	6-7	3351	76	14.4
	Ae africanus	21	2.3	12	1.1	75	4.6	6	0.8	7-8	114	2.6	
	Ae luteocephalus									7-8			
	Ae vittatus	32	3.5	73	6.8	83	5.2	46	5.9	8-9	234	5.3	
	Toxorhynchites	53	5.7	17	1.6	35	2.2	28	3.6	6-10	133	3.0	
	Other mosq.	91	9.8	125	11.6	264	16.4	76	9.8	6-8	556	12.7	
	TOTALS	925	100	1077	100	1610	100	776	100		4388		
SEPTEMBER	Ae aegypti	815	77.5	683	77	1294	73.9	531	87	6-7	3323	77	14.1
	Ae africanus			12	1.4	86	4.9			7-8	98	2.3	
	Ae luteocephalus	41	3.9					25	4.1	7-8	66	1.5	
	Ae vittatus			56	6.2	57	3.3	16	2.6	8-9	129	3.0	
	Toxorhynchites	31	2.9	12	1.4	42	2.4	17	2.8	6-10	102	2.4	
	Other mosq.	165	15.7	124	13.9	270	15.4	21	3.4	6-8	580	13.5	
	TOTALS	1052	100	887	100	1749	100	610	100		4298		

TABLE 3 COMPARISON OF MONTHLY MOSQUITO LARVAL FREQUENCIES ON UST CAMPUS (KUMASI) SHOWING VARIOUS MOSQUITO SPECIES AND THE PH OF THEIR RESPECTIVE HABITATS

MONTH	MOSQUITO SPECIES	SWAMP		BOTANICAL GARDENS		IRRIGATED FARMLANDS		DEPARTMENTS & ADMIN. BLK		HALLS		SENIOR STAFF RESIDENCE		JUNIOR STAFF RESIDENCE		ORANGE ORCHARD	
		TOTAL	%	TOTAL	%	TOTAL	%	TOTAL	%	TOTAL	%	TOTAL	%	TOTAL	%	TOTAL	%
FEBRUARY (1987)	Aedes aegypti	134	73	223	85	71	86	193	95	132	99	544	92	121	86	117	51
	Ae Africanus	46	25														
	Ae luteocephalus			30	12												
	Ae vittatus					1	1	5	2	1	1	8	2	4	3	1	1
	Toxorhynchites	3	2	8	3	10	13	5	3					16	11	112	48
	Other mosquitoes																
	TOTALS	183	100	261	100	82	100	203	100	133	100	552	100	141	100	230	100
MARCH	Aedes aegypti	1346	96	2068	96	1194	73	1726	82	1004	84	2071	90	734	86	847	67
	Ae. africanus	23	2					182	9								
	Ae luteocep.																
	Ae vittatus			59	3												
	Toxorhynchites	19	2	9	1	25	2	57	3	51	5	98	4	21	3	15	1
	Other mosq.					403	25	135	6	136	11	126	6	94	11	398	32
	TOTAL	1388	100	2136	100	1622	100	2100	100	1191	100	2295	100	849	100	1260	100
APRIL	Aedes aegypti	1424	83	618	79	1065	79	1950	72.3	1369	87	795	90	740	80.5	842	55
	Ae Africanus	249	15					264	10.0								
	Ae luteocep	18						35	1.3					28	3.0		
	Ae vittatus			82													
	Toxorhynchites	37	2	16	2	19	1	126	4.7	54	3	50	6	61	6.6	8	1
	Other mosq.	6	1		19	258	19	307	11.4	159	10	31	4	90	9.8	666	44
	TOTALS	1734	100	716	100	1342	100	2682	100	1582	100	876	100	919	100	1516	100
MAY	Aedes aegypti	3542	94	1085	58	496	57	1501	85	1627	92	901	92	1130	93	46	18
	Ae Africanus	122						128	7								
	Ae luteocephalus																
	Ae vittatus			204													
	Toxorhynchites	80	2	49	1	3	1	40	0	48	3	59	6	26	2	0	0
	Other mosq.	15	1		42	371	52	139	8	95	5	17	2	55	5	210	82
	TOTALS	3759	100	1338	100	870	100	1808	100	1770	100	977	100	1211	100	256	100
JUNE	Aedes aegypti	3338	87	1699	77	259	55	917	77	3653	90.7	3109	85	3019	87	342	82
	Ae Africanus	387	10					69	6	55	1.4	20	1	20	0.6		6
	Ae luteocep.	12	1							23	.6			22	0.6		
	Ae vittatus		1	486	22									31	0.9		
	Toxorhynchites	36	1	9	1	2	1	20	2	107	2.6	178	5	79	2.3	3	1
	Other mosq.	63				211	44	171	15	189	4.6	315	9	293	8.5	69	17
	TOTALS	3836	100	2194	100	472	100	1177	100	4025	100	3622	100	3464	100	414	100
JULY	Ae aegypti	2977	75	1897	56	830	57	2654	83	3000	61	2707	90	2564	90	1190	93
	Ae Africanus	845	20					374	12	33	7	18	1	20	2		
	Ae luteocep.	7	1	29	0.8												
	Ae vittatus			1483	43									55	2		
	Toxor.	11	1	12	1	9	1	23	1	32	7	113	4	24	1	4	1
	Other Mosq.	113	3			613	42	156	4	125	25	166	5	126	4	85	7
	TOTALS	3953	100	3421	100	1452	100	3207	100	3190	100	3004	100	2839	100	1279	100
AUGUST	Ae aegypti	1042	68	1108	58	608	59	1740	74	1928	81	1097	81	1087	86	1401	73
	Ae Africanus	284	18					243	10	80	3	45	3	23	2		
	Ae luteocep.																
	Ae vittatus			733	39									14	1		
	Toxor.	34	2	59	3	35	3	33	1	26	1	37	3	23	2	41	2
	Other Mosq.	174	12			385	37	365	15	357	15	171	13	111	9	481	25
	TOTALS	1534	100	1900	100	1028	100	2341	100	2391	100	1350	100	1258	100	1923	100
SEPTEMBER	Ae aegypti	1610	70	1517	76	651	60	1547	68	2275	85	1597	84	683	75	1552	6
	Ae Africanus	341	15					277	12	116	4	24	2	15	2		
	Ae Luteocep.																
	Ae vittatus			438	22									17	9		
	Toxor.	62	3	49	2	23	2	16	1	49	2	96	5	29	3	35	2
	Other Mosq.	278	13			401	38	425	20	241	9	179	9	102	11	656	29
	TOTALS	2291	100	2004	100	1075	100	2265	100	2681	100	1896	100	846	100	2243	100
OCTOBER	Ae aegypti	520	77	426	68	261	50	1271	76	856	75	688	79	272	77	903	78
	Ae Africanus	54	8					55	3	39	3	5	1	0	-		
	Ae Luteocep.																
	Ae vittatus			184	29									11	3		
	Toxor.	43	6	21	3	30	5	40	3	28	3	69	7	16	5	15	1
	Other Mosq.	62	9			236	45	308	18	217	19	112	13	59	15	237	21
	TOTALS	679	100	631	100	527	100	1674	100	1140	100	874	100	352	100	1155	100
NOVEMBER	Ae aegypti	29	61	16	52	11	55	52	78	12	71	38	76	24	83	38	52
	Ae Africanus	5	10							0		0					
	Ae Luteocep.																
	Ae Vittatus			10	32												
	Toxor.	13	27	5	16	4	20	8	12	5	29	4	8	5	17	13	18
	Other Mosq.	1	2			5	25	7	10			8	16			24	30
	TOTALS	48	100	31	100	20	100	67	100	17	100	50	100	29	100	75	100
DECEMBER	Ae aegypti					6	75									14	58
	Ae Africanus																
	Ae Luteocep.																
	Ae Vittatus																
	Toxor.					0	-									3	13
	Other Mosq.					2	25									7	29
	TOTALS	0		0		8	100	0		0	100	0				24	100
	Ae aegypti					4	67										
	Ae Africanus																
	Ae Luteocep.																

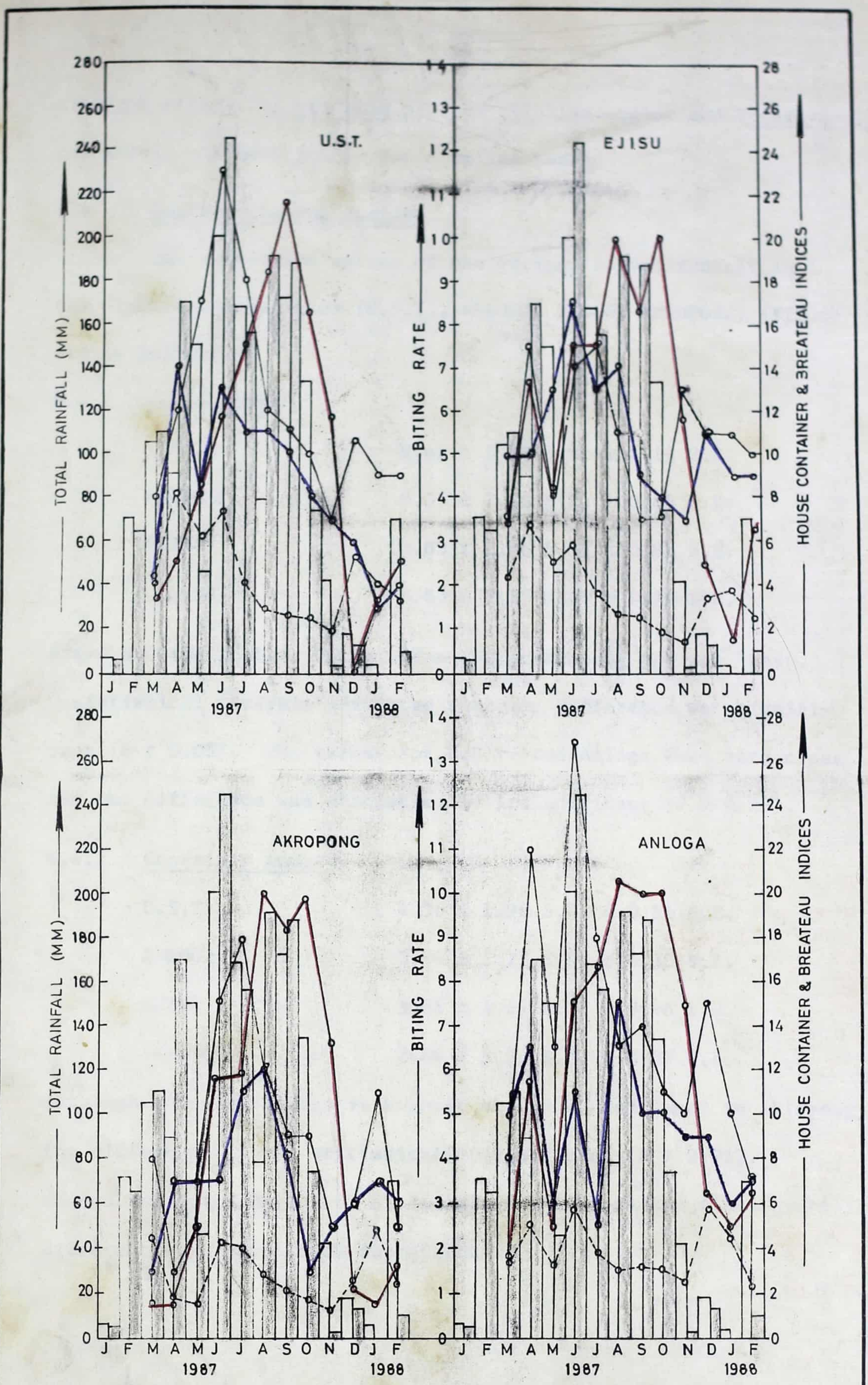

FIG 5 GRAPHS SHOWING THE VECTOR INDICES AT THE VARIOUS LOCALITIES IN RELATION TO THE MEAN RAINFALL FOR 10 YEARS 1977–1986 AND 1987/88

KEY

BITING RATE (BR)
HOUSE INDEX (HI)
CONTAINER INDEX (CI)
BRETEAU INDEX (BI)
AV. RAINFALL 1977–1986
RAINFALL 1987/88

alkaline media. Ae vittatus prefers alkaline medium and Toxorhynchites can survive in both acidic and alkaline media.

6.4 Mosquito Larval Indices

The respective values of the various larval indices in the different localities (U.S.T., ANLOGA, EJISU, AKROPONG) (Fig.5) are as follows:

6.4.1 House Index

U.S.T.	8.42 ± 3.89 S.D. ± 1.12 S.E.
ANLOGA	9.25 ± 2.96 S.D. ± 0.85 S.E.
EJISU	10.83 ± 2.88 S.D. ± 0.83 S.E.
AKROPONG	6.83 ± 2.55 S.D. ± 0.74 S.E.

Ejisu has the highest House index while Akropong has the least. A statistical analysis indicated that this difference was significant ($P < 0.05$). The values for U.S.T. and Anloga were very close and the difference was statistically insignificant ($P > 0.05$).

6.4.2 Container index

U.S.T.	4.36 ± 1.96 S.D. ± 0.56 S.E.
ANLOGA	3.84 ± 1.21 S.D. ± 0.35 S.E.
EJISU	3.65 ± 1.61 S.D. ± 0.46 S.E.
AKROPONG	2.84 ± 1.2. S.D. ± 0.35 S.E.

Although container index is highest at U.S.T. and least in Akropong the difference is not statistically significant ($P > 0.05$).

Anloga and Ejisu have close values which are not significantly different ($P > 0.05$).from the others.

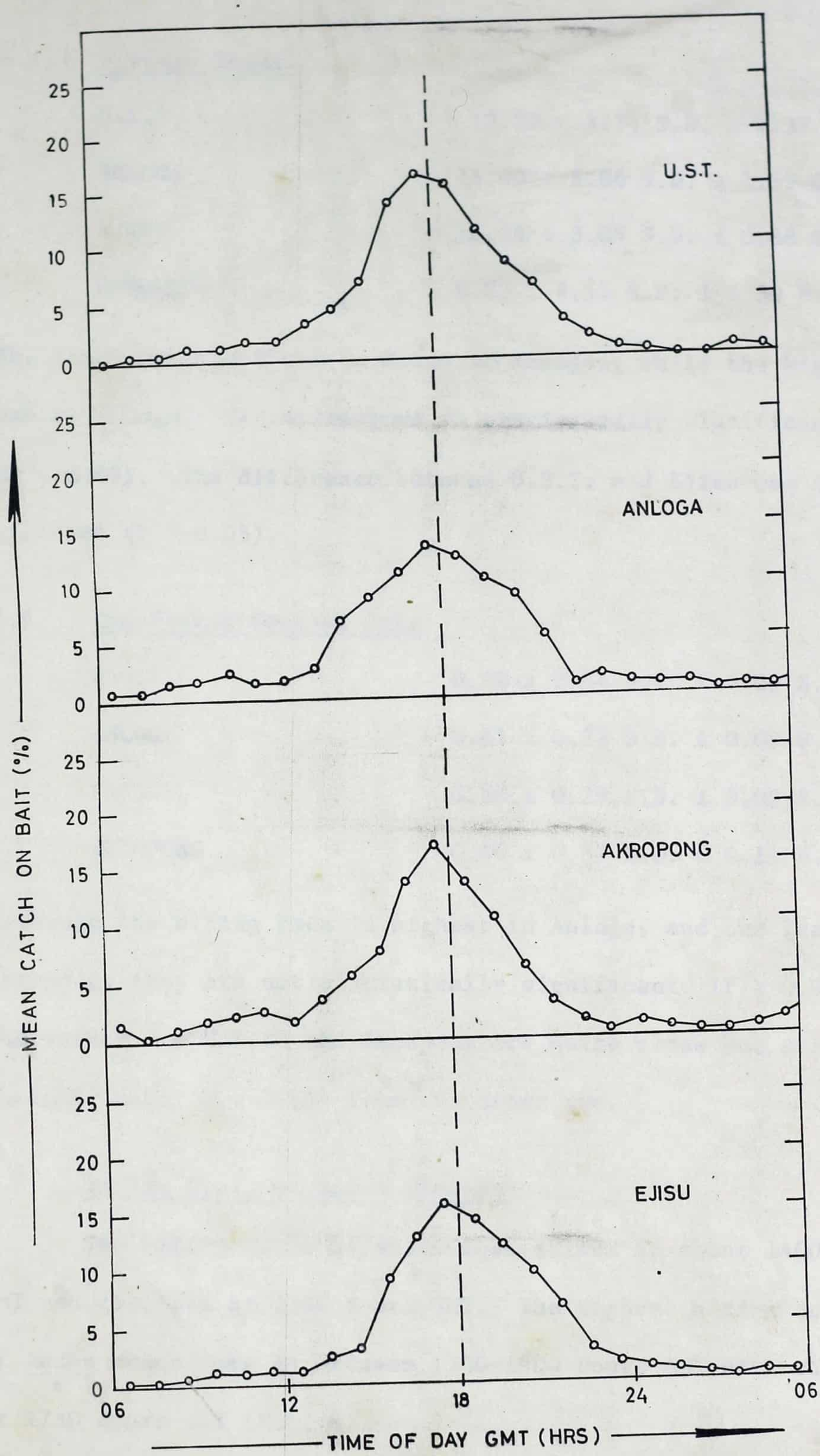

FIG.6 BITING CYCLES OF AEDES (STEGOMYIA) AEGYPTI LINNAEUS IN 4 LOCALITIES

6.4.3 Breteau Index

U.S.T.	12.23 ± 4.74 S.D. ± 1.37 S.E.
ANLOGA	14.00 ± 5.86 S.D. ± 1.69 S.E.
EJISU	12.23 ± 3.05 S.D. ± 0.88 S.E.
AKROPONG	8.83 ± 4.51 S.D. ± 1.30 S.E.

The least Breteau index is found at Akropong while the highest was at Anloga. The difference is statistically significant ($P < 0.05$). The difference between U.S.T. and Ejisu was insignificant ($P > 0.05$).

6.5 Man-Vector Contact Rate

U.S.T.	0.40 ± 0.34 S.D. ± 0.09 S.E.
ANLOGA	0.61 ± 0.33 S.D. ± 0.09 S.E.
EJISU	0.58 ± 0.29 S.D. ± 0.09 S.E.
AKROPONG	0.46 ± 0.37 S.D. ± 0.11 S.E.

Although the biting rate is highest in Anloga, and the least in Akropong, they are not statistically significant. ($P > 0.05$).
The values for U.S.T. and Akropong are quite close but statistically insignificant ($P > 0.05$) from the other two.

6.6 Biting Cycle of Aedes Species

The biting cycle of mosquitoes starts at about 1400 Hours GMT and declines at 2200 Hours GMT. The highest biting activity of Aedes mosquitoes is between 1700-1900 Hours GMT with the peak at 1730 Hours GMT (Fig. 6).

The highest percentage of mosquitoes caught at the peak of the biting is 15.5%. The lowest is between the hours of 0700-0800 Hours GMT and 1400-1500 Hours GMT.

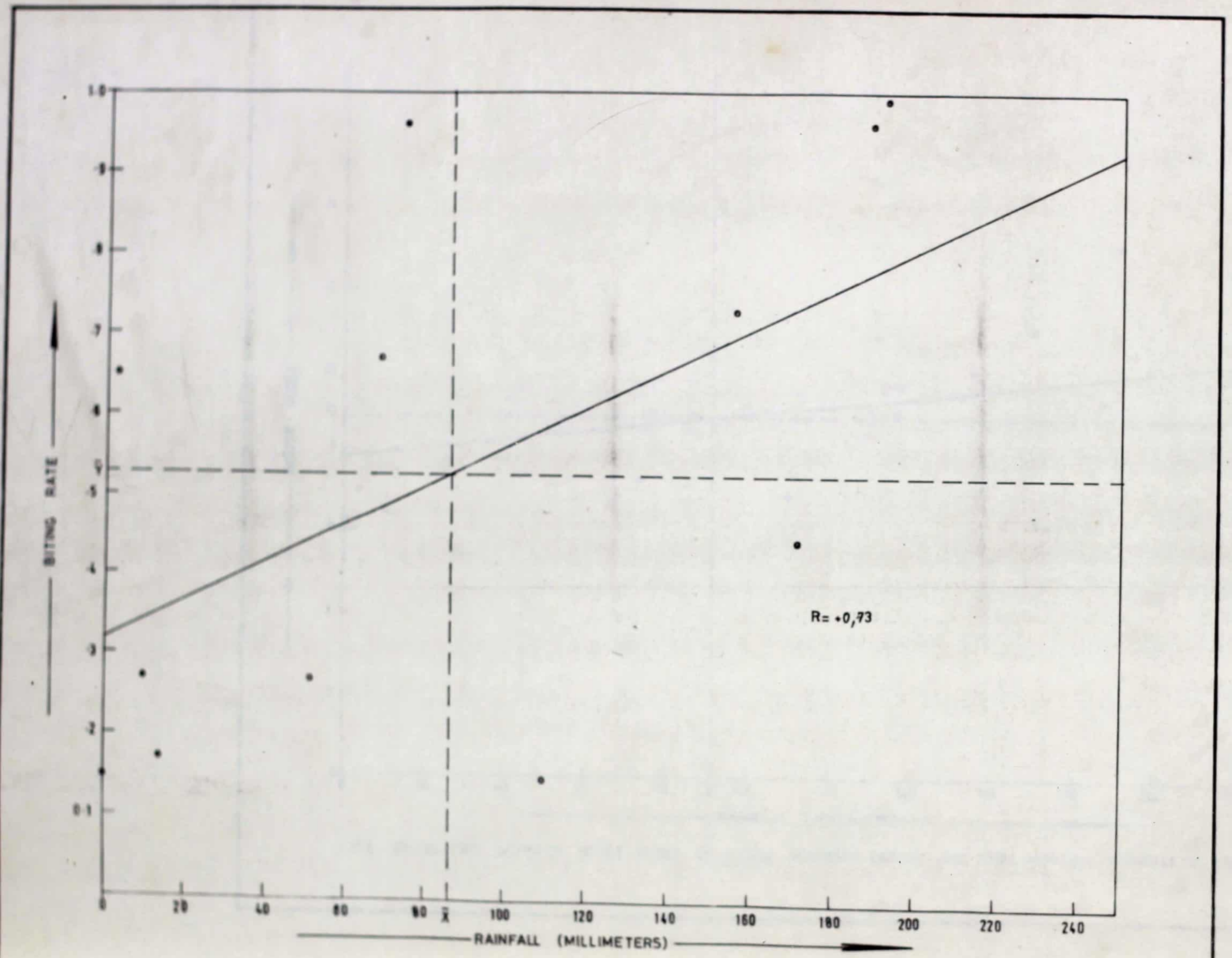

FIG 7 CORRELATION BETWEEN DIC BITING RATE (MAN VECTOR CONTACT) OF AEDES MOSQUITOES AND ANNUAL RAINFALL IN THE ARUSHA REGION

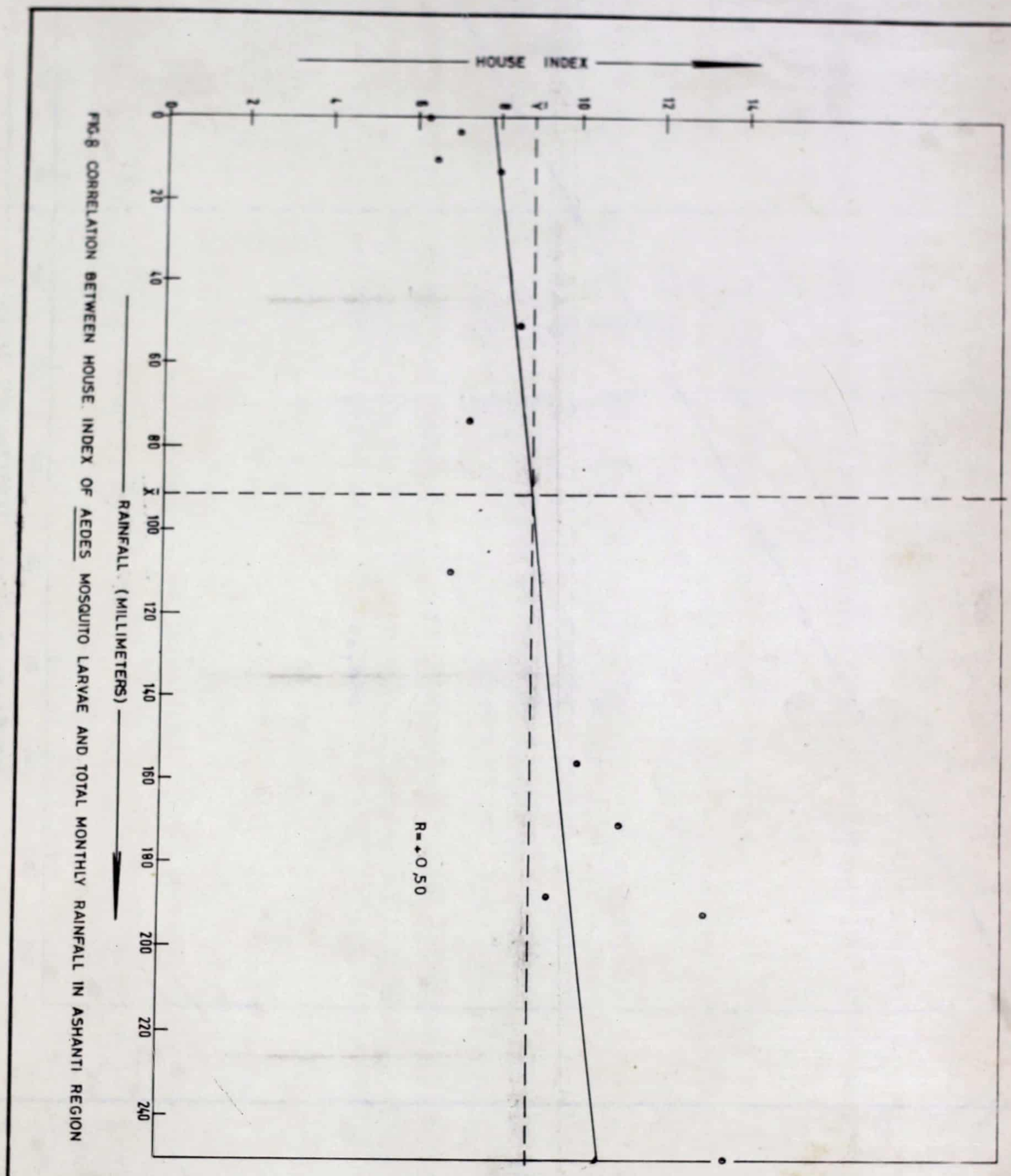

FIG.8 CORRELATION BETWEEN HOUSE INDEX OF AEDES MOSQUITO LARVAE AND TOTAL MONTHLY RAINFALL IN ASHANTI REGION

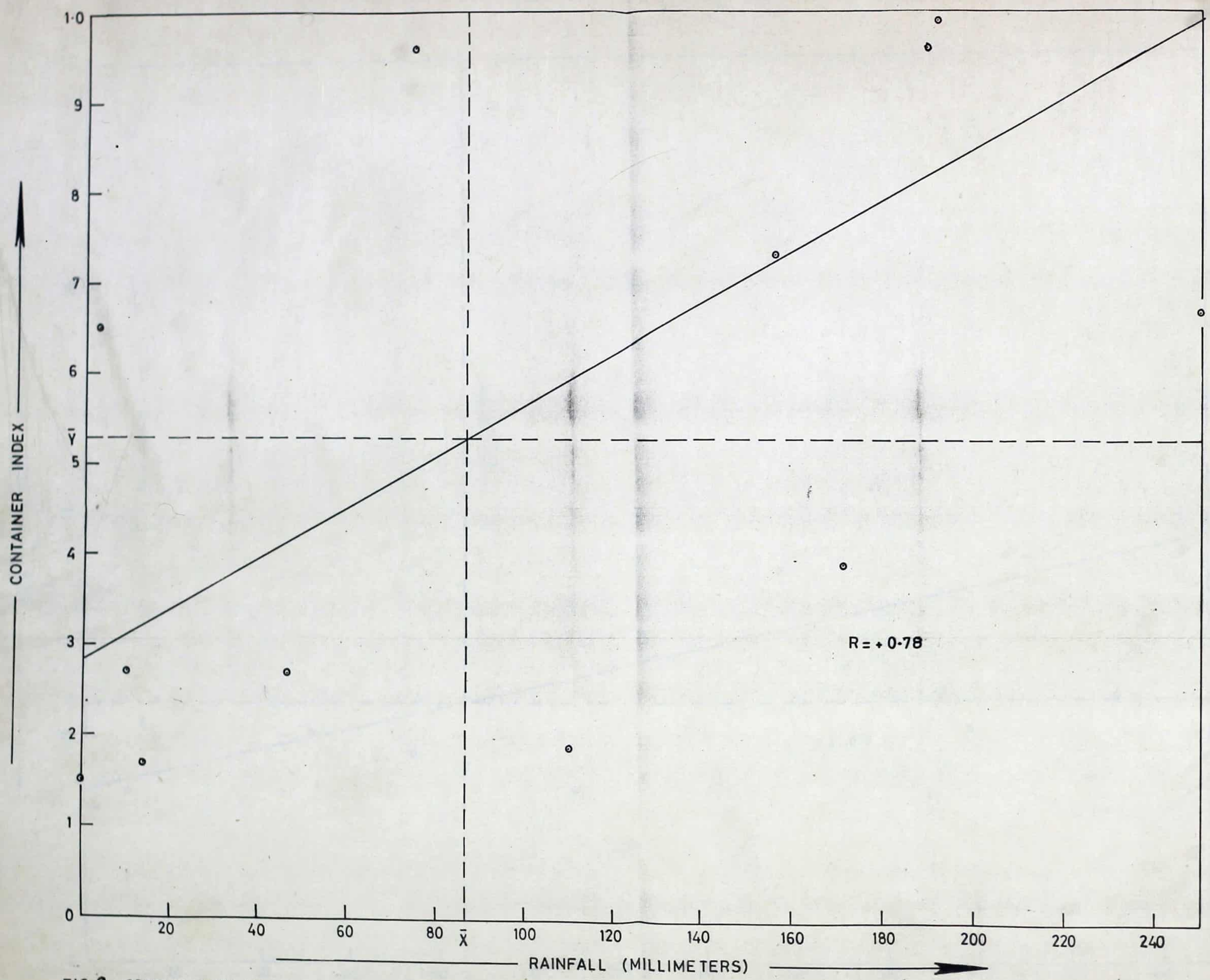

FIG. 9 CORRELLATION BETWEEN CONTAINER INDEX OF AEDES MOSQUITO LARVAE AND THE TOTAL MONTHLY RAINFALL IN THE ASHANTI REGION

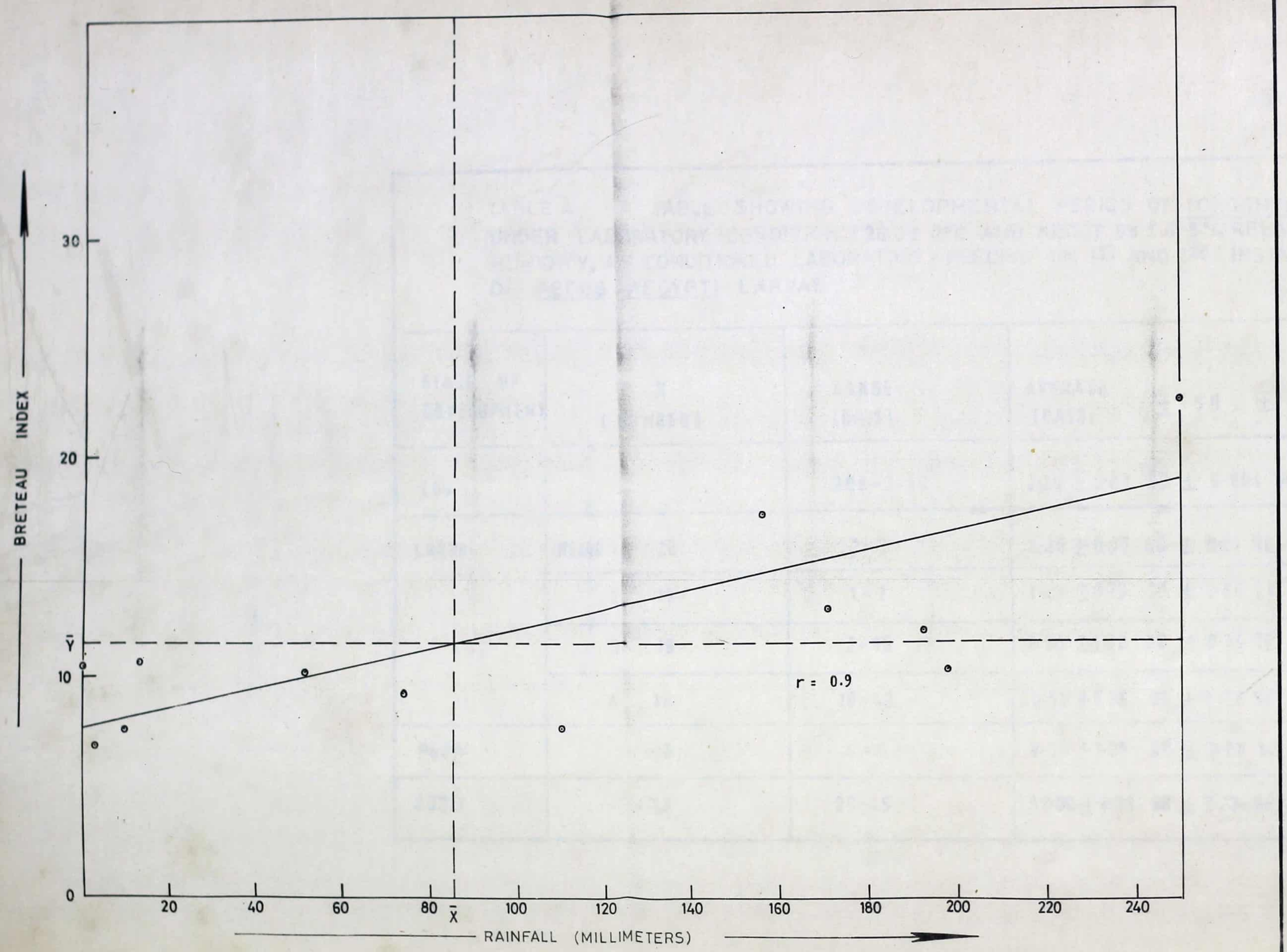

FIG.10 CORRELATION BETWEEN BRETEAU INDEX OF AEDES MOSQUITO LARVAE AND TOTAL MONTHLY RAINFALL IN THE ASHANTI REGION.

TABLE 4 A TABLE SHOWING DEVELOPMENTAL PERIOD OF TOXORHYNCHITES UNDER LABORATORY CONDITION (26·0 ± 2°C AND ABOUT 68 ± 4·5% RELATIVE HUMIDITY, AIR CONDITIONED LABORATORY) FEEDING ON 1ST AND 2ND INSTARS OF OF AEDES AEGYPTI LARVAE

STAGE OF DEVELOPMENT	N (NUMBER)	RANGE (DAYS)	AVERAGE (DAYS) ± SD ± SE
EGG		2·08–2·40	2·20 ± 0·02 SD ± 0·004 SE
LARVA	INSTAR 1 20	2–3	2·35 ± 0·05 SD ± 0·01 SE
	2 19	1–2	1·25 ± 0·26 SD ± 0·06 SE
	3 19	2–15	8·50 ± 1·50 SD ± 0·34 SE
	4 18	16–43	29·50 ± 5·35 SD ± 1·26 SE
PUPA	16	4–6	5·20 ± 1·05 SD ± 0·26 SE
ADULT	13	20–45	30·00 ± 8·05 SD ± 2·23 SE

TABLE 5 A TABLE SHOWING HEAD CAPSULE WIDTH MEASUREMENTS OF TOXORHYNCHITES LARVAL INSTARS

LARVAL INSTAR	N (NUMBER)	RANGE (MM)	AVERAGE ± S D ± S E (MM)
FIRST INSTAR	10	0·30 — 0·50	0·35 ± 0·03 SD ± ·009 SE
SECOND INSTAR	10	0·50 — 0·60	0.56 ± 0·24 SD ± ·08 SE
THIRD INSTAR	10	0·90 — 1·05	0·95 ± 0·04 SD ± ·01 SE
FOURTH INSTAR	10	1·30 — 1·65	1·50 ± 0·06 SD ± ·02 SE

The correlation graphs of Rainfall against Biting Rate, House Index, Container index and Breteau index are plotted in Figures 7,8,9 and 10 respectively to show their respective correlations. It is observed from the plot that the correlation coefficients(r) are as follows: Biting Rate = 0.73, House Index = 0.50, Breteau Index = 0.9 and Container Index = 0.78. The significant parameters ($P < 0.05$) were Biting Rate, Breteau Index and container Index.

Again, the graphs of Relative Humidity at 1500 Hours GMT was plotted against biting Rate, House index, Container index and Breteau index as shown in figures 11, 12, 13 and 14 respectively. The respective correlation coefficients (r) were: Biting Rate = 0.65, House index = 0.69, Breteau index = 0.50 and Container index =-0.08.

The Biting Rate, House index and Breteau index all have positive correlation with the percentage relative humidity, while the container index has a negative correlation. However, statistical tests of the graphs show that the Biting Rate and House index had significant correlation ($P < 0.05$) with the Relative Humidity.

6.7 Life-span of Larval Instars of Toxorhynchites

The developmental period of Toxorhynchites under laboratory condition is shown in Table 4 and the width of the head capsules of larval instars in Table 5.

There are 4 larval instars. The egg lasted for about 2.08-2.40 days. The first larval instar was 2-3 days and had a mean of 2.3 days ± 0.05 S.D. ± 0.01 S.E. The second larval instar was 1-2 days and a mean of 1.25 days ± 0.26 S.D. ± 0.06 S.E. The third larval instar was 2-15 days and a mean of 8.50 days ± 1.50 ± 0.35 S.E. The fourth larval instar was 16-43 days and a mean of 29.50

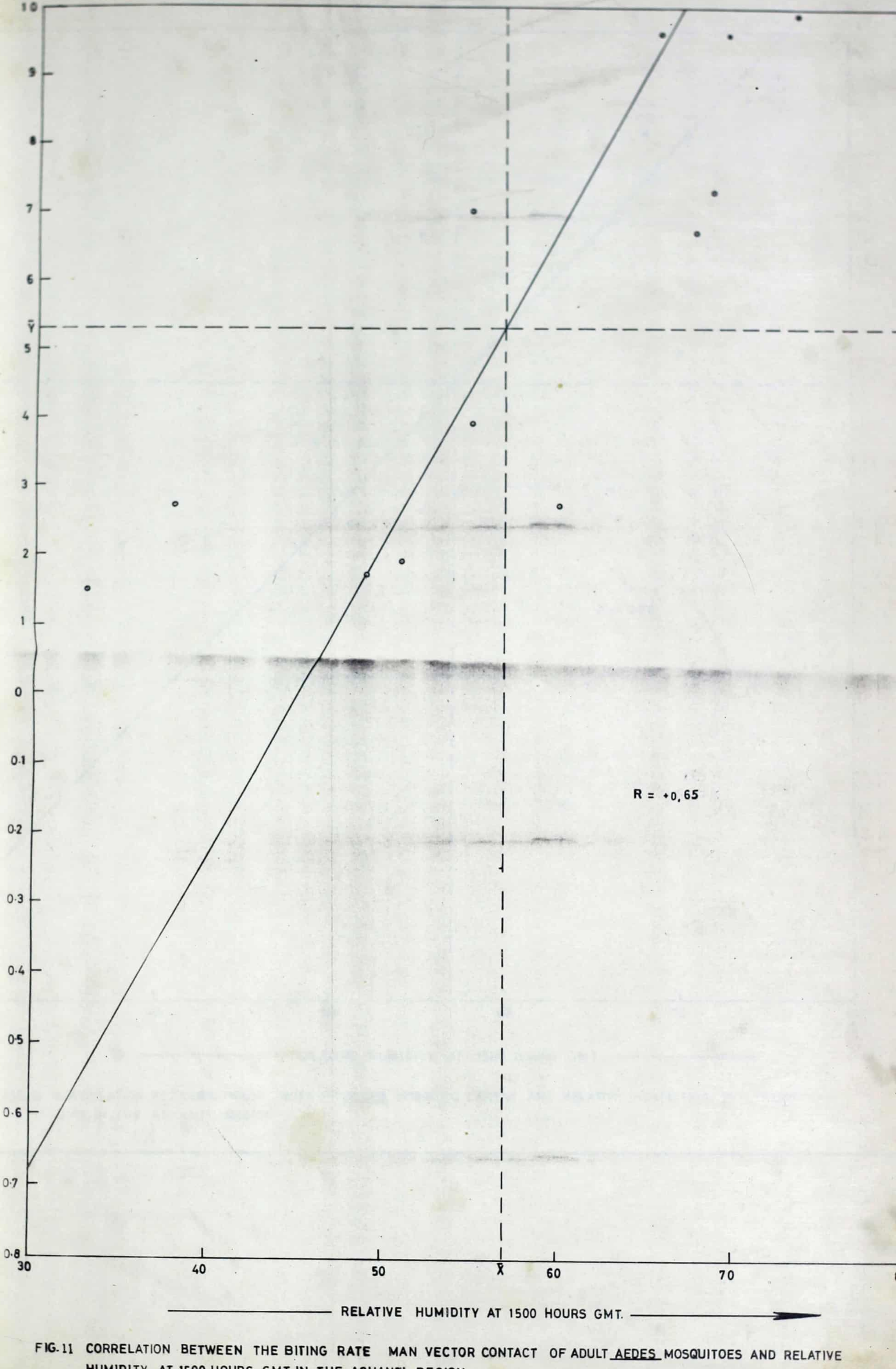

FIG. 11 CORRELATION BETWEEN THE BITING RATE MAN VECTOR CONTACT OF ADULT AEDES MOSQUITOES AND RELATIVE HUMIDITY AT 1500 HOURS GMT IN THE ASHANTI REGION

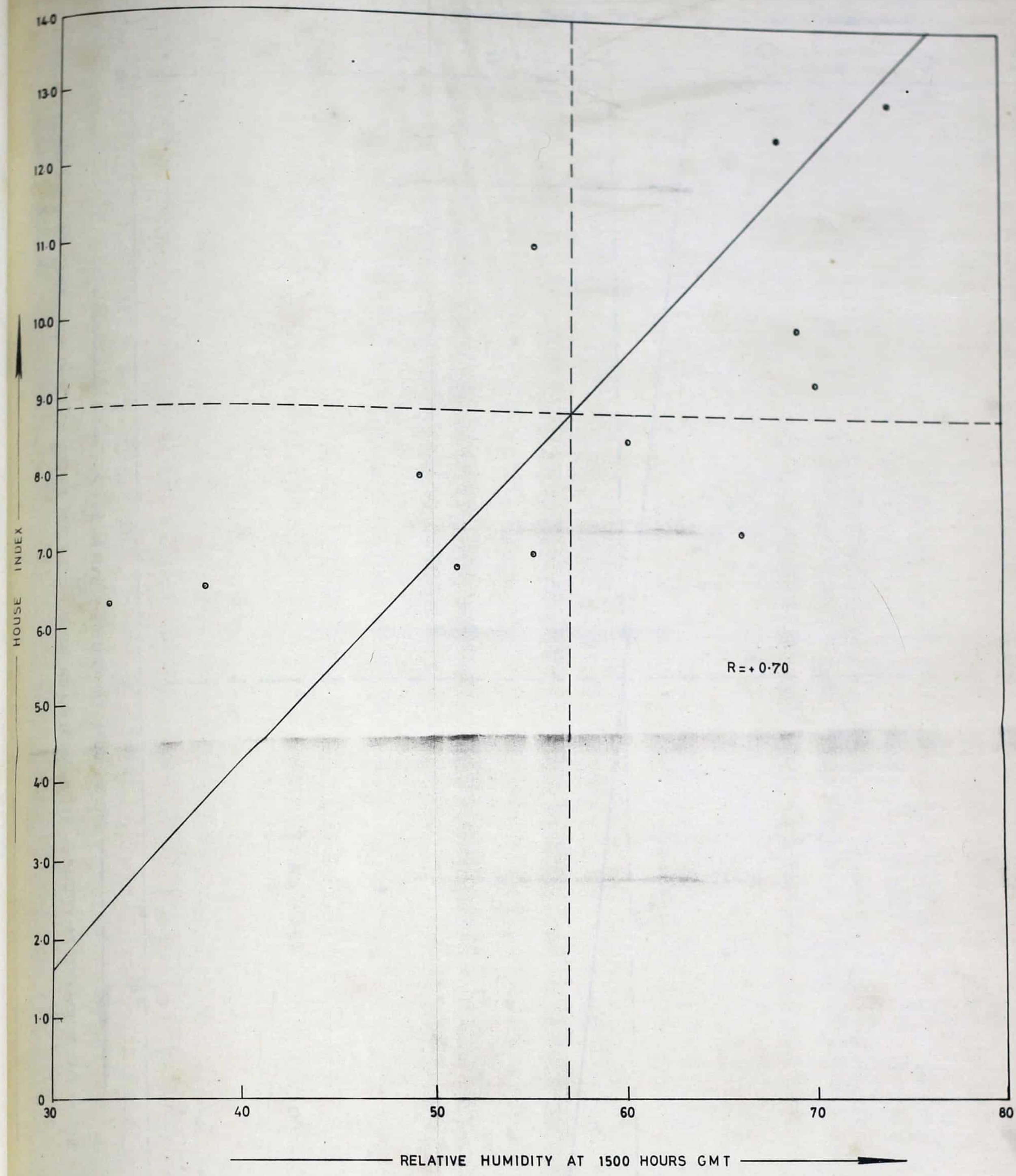

FIG. 12 CORRELATION BETWEEN HOUSE INDEX OF AEDES MOSQUITO LARVAE AND RELATIVE HUMIDITY AT 1500 HOURS GMT IN THE ASHANTI REGION

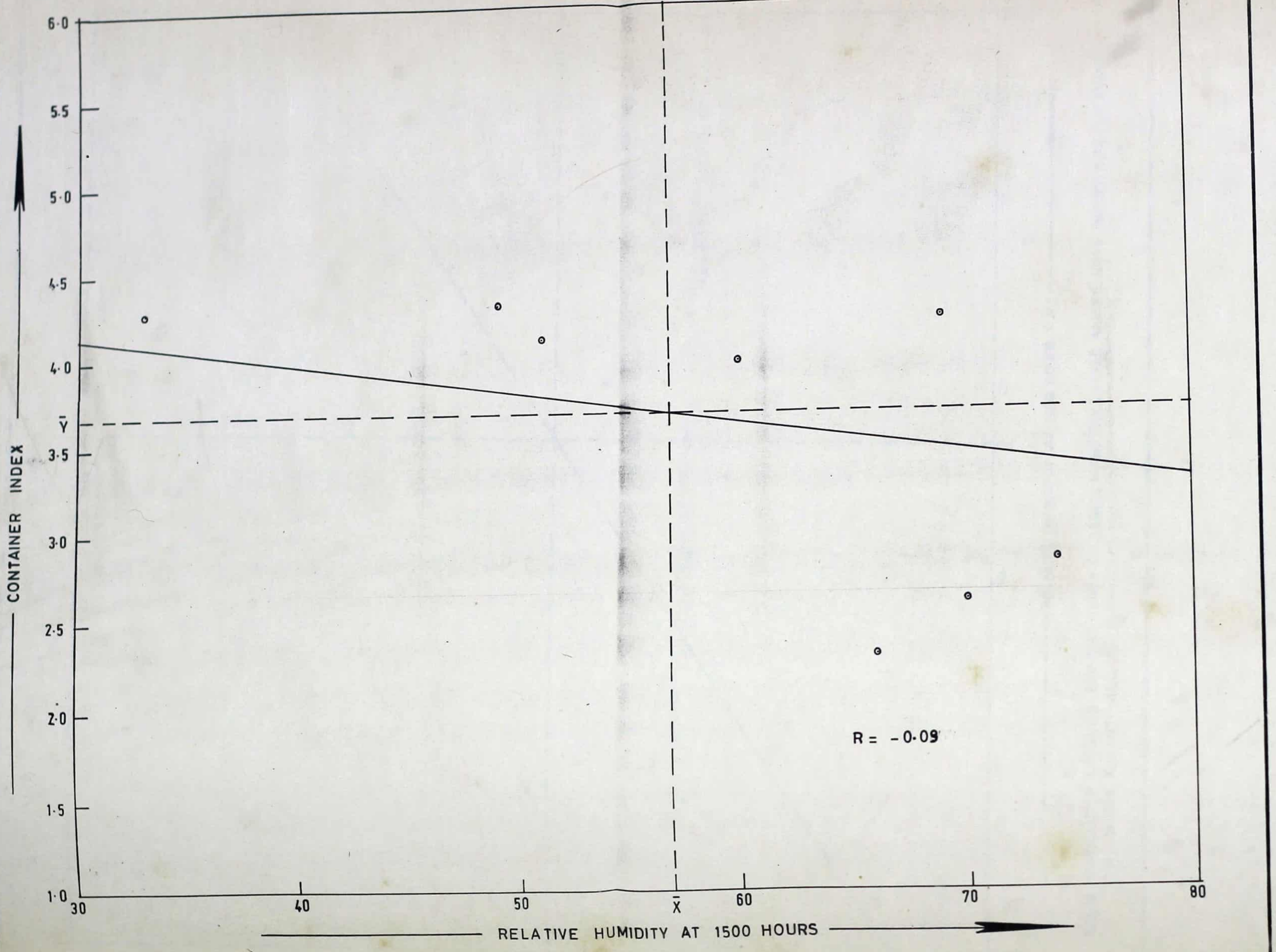

FIG. 13 REGRESSION OF CONTAINER INDEX OF AEDES MOSQUITO LARVAE AGAINST RELATIVE HUMIDITY AT 1500 HOURS GMT IN THE ASHANTI REGION.

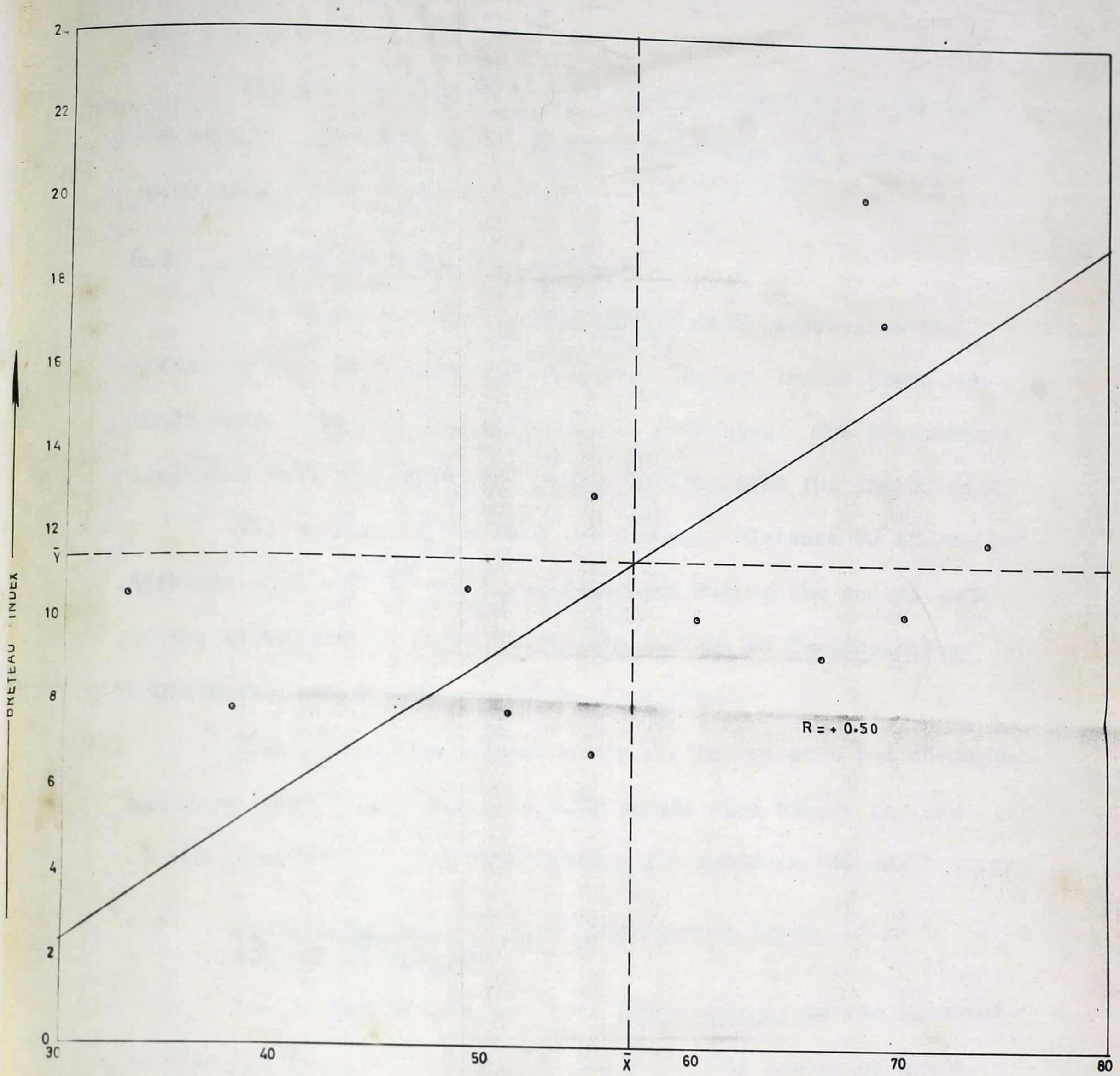

FIG. 14 CORRELATION BETWEEN BRETEAU INDEX OF AEDES MOSQUITO LARVAE AND RELATIVE HUMIDITY AT 1500 HOURS G M T IN THE ASHANTI REGION.

days ± 5.35 S.D. ± 1.26 S.E.

The pupa was 4-6 days and a mean of 5.20 days ± 1.05 S.D. ± 0.26 S.E. The adult had a range of 20-45 days and a mean of 30.00 days ± 8.05 S.D. ± 2.23 S.E.

6.8 Starvation of Toxorhynchites

The number of dead Toxorhynchites after starvation for different days is recorded in Table 6. The 1st instar lived for 10-25 days. The 2nd instars lived for 4-15 days. The 3rd instars lived for 9-65 days while the 4th instars endured for 20-100 days.

The fourth instars show the highest tolerance to starvation. Although about 10% of the insects pupated before the end of each of the experiment, some of the fourth instars of Toxorhynchites could endure for 90-100 days without pupation.

A control experiment where the larvae were fed throughout the experiment shows that only 7.5% larvae died before the end of the experiments. The other larvae developed to the adult stage.

6.9 Feeding Capacity of Toxorhynchites on Aedes aegypti Mosquitoes

The number of second instar Aedes aegypti larvae consumed by Toxorhynchites is recorded in Table 7. The number of Aedes aegypti larvae consumed by first instar Toxorhynchites ranged 6-15 and a mean of 8.6 ± 1.52 S.D. ± 0.48 S.E. The second instars consumed 4-11 and a mean of 6.5 ± 1.10 S.D. ± 0.35 S.E. The third instars consumed 10-80 larvae and a mean of 37.03 ± 6.80 S.D. ± 2.15 S.E. The fourth instars consumed 185-432 and a mean of 268.05 ± 49.31 S.D. ± 15.59 S.E.

TABLE 6 MORTALITY OF TOXORHYNCHITE BREVIPALPIS THEO AFTER STARVATION OF VARIOUS INSTARS

DEVELOPMENTAL STAGES		NUMBER OF DEAD LARVAE AFTER PERIODS OF STARVATION (IN DAYS)																					
EXPT	INSTARS	1	2	3	4	5	6	7	8	9	10	12	15	20	25	30	35	40	45	50	55	60	65
1	1	0	0	0	0	0	0	0	0	0	1	3	4	2	0	0	0	0	0	0	1	0	0
	2	0	0	0	3	0	0	1	0	0	0	4	1	1	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	1	0	1	0	0	2	3	0	1	0	0	1	0	1
	4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	2
2	1	0	0	0	0	0	0	0	0	0	0	4	3	2	1	0	0	0	0	0	0	0	0
	2	0	0	0	2	0	1	1	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	1	1	0	0	2	2	0	2	0	0	1	0	1
	4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	2	0
3	1	0	0	0	0	0	0	0	0	0	0	3	3	2	2	0	0	0	0	0	0	0	0
	2	0	0	0	2	0	0	1	1	0	0	4	2	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	2	1	0	0	3	1	0	1	0	0	1	0	1
	4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	1	0	1	0
4	1	0	0	0	0	0	0	0	0	0	2	3	2	2	1	0	0	0	0	0	0	0	0
	2	0	0	0	1	1	0	3	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	2	1	0	0	1	3	0	0	2	0	0	1	0
	4	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	0	1	0	1	0
5 (CONTROL)	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 7 A TABLE SHOWING NUMBER OF SECOND INSTAR AEDES AEGYPTI LARVAE CONSUMED BY TOXORHYNCHITES BREVIPALPIS THEOBALD

LARVAL INSTAR	N	RANGE	AVERAGE ± SD ± SE
FIRST INSTAR	10	6—15	8·6 ± 1·52 SD ± 0·48 SE
SECOND INSTAR	10	4—11	6·5 ± 1 10·SD± 0·35 SE
THIRD INSTAR	10	13—80	37·03± 6·80 SD± 2·15 SE
FOURTH INSTAR	10	185—432	268·05± 49·31 SD± 15·59·SE

6.10 Feeding Preference of Toxorhynchites on Different Species of Mosquitoes

Results from experiments as shown in Table 8 shows that Toxorhynchites significantly ($P < 0.01$) prefer Aedes aegypti larvae to Culex decens and Anopheles gambiae. There was however no significant difference in the choice between Culex decens and Anopheles gambiae ($P > 0.05$). In a Laboratory experiment the numbers of Aedes aegypti, Culex decens and Anopheles gambiae consumed by Toxorhynchites were 598, 187 and 228 respectively. The respective means consumed per day were as follows: Aedes aegypti 23.71 ± 7.24 S.D. ± 1.58 S.E. Culex decens 8.91 ± 4.08 S.D. ± 0.89 S.E. and Anopheles gambiae 10.86 ± 3.29 S.D. ± 0.72 S.E.

6.11 Distribution of Toxorhynchites Species in the Study Area

Records of the distribution of Toxorhynchites species in the various localities on the University Campus are shown in Table 9. The most preferred microhabitat is tree-holes. About 69.49% of total Toxorhynchites caught were sampled from tree-holes. Lorry tyres which form about 6.49% of total microhabitats is the next preferred microhabitat. The least preferred microhabitat is faulty sink which gave about 0.57%.

There were 12 microhabitats in all and their respective values are as follows: Tree-holes 69.49%, Lorry tyres 6.49%, water tank 0.89%, water jar 2.42$, irrigation canal 2.03%, crab-holes 3.31%, Tin-Can 4.14%, Rock pools 0.96%, Ground pools 5.35%, ponds 2.55%, drains 1.78% and faulty sink 0.57%.

The pH range of the microhabitats is highest at the Botanical Garden (pH 6-10) and mainly in the tree-holes (pH 6-7), drains and rock pools (pH 9-10).

TABLE 8 FEEDING PREFERENCE OF TOXORHYNCHITES BREVIPALPIS THEOBALD ON DIFFERE

EXPERIMENT (1 - 10)	DAYS (EXPT. 1-10)	NUMBER OF MOSQUITOES EATEN			
		AEDES AEGYPTI		CULEX DECENS	
		TOTAL	MEAN ± S.D. ± S.E.	TOTAL	MEAN ± S
1	1	35	3.5 ± 1.50SD ± 0.47SE	18	1.8 ± 1.23
	2	27	2.7 ± 1.65SD ± 0.52SE	8	0.8 ± 0.63
	3	19	1.9 ± 1.59SD ± 0.53SE	7	0.7 ± 0.82
	4	38	3.8 ± 2.39SD ± 0.79SE	14	1.4 ± 1.26
	5	31	3.1 ± 1.52SD ± 0.51SE	15	1.5 ± 1.08
	6	26	2.6 ± 1.07SD ± 0.36SE	12	1.2 ± 0.92
	7	28	2.8 ± 1.37SD ± 0.46SE	5	0.5 ± 0.71
TOTAL		204	29.14±6.25SD±3.36SE	79	11.2±4.75
2	8	10	1.0 ± 0.81SD ± 0.27SE	8	0.8 ± 1.07
	9	17	1.7 ± 0.95SD ± 0.31SE	3	0.3 ± 0.67
	10	16	1.6 ± 1.50SD± 0.50SE	5	0.5 ± 0.71
	11	21	2.1 ± 1.2SD ± 0.40SE	3	0.3 ± 0.55
	12	25	2.5 ± 0.85SD ± 0.28SE	7	0.7 ± 1.01
	13	19	1.9 ± 1.73SD ± 0.58SE	8	0.8 ± 1.03
	14	21	2.1 ± 0.52SD ± 0.51SE	8	0.8 ± 0.92
TOTAL		129	18.43 ± 4.76SD ± 1.79SE	42	6.0 ± 2.31
3	15	23	2.3 ± 0.46SD ± 0.15SE	9	0.9 ± 1.10
	16	15	1.5 ± 1.18SD ± 0.39SE	10	1.0 ± 1.15
	17	18	1.8 ± 1.65SD ± 0.55SE	5	0.5 ± 0.71
	18	31	3.1 ± 1.79SD ± 0.59SE	12	1.5 ± 1.03
	19	19	1.9 ± 1.37SD ± 0.46SE	7	0.7 ± 0.95
	20	33	3.3 ± 1.70SD ± 0.57SE	8	0.8 ± 1.03
	21	26	2.6 ± 1.65SD ± 0.55SE	15	1.5 ± 1.03
TOTAL		165	23.57 ± 6.78SD ± 2.56SE	66	9.42 ± 3.3
GRAND TOTALS		498	23.71 ± 7.24SD ± 1.58SE	187	8.91 ± 4.0

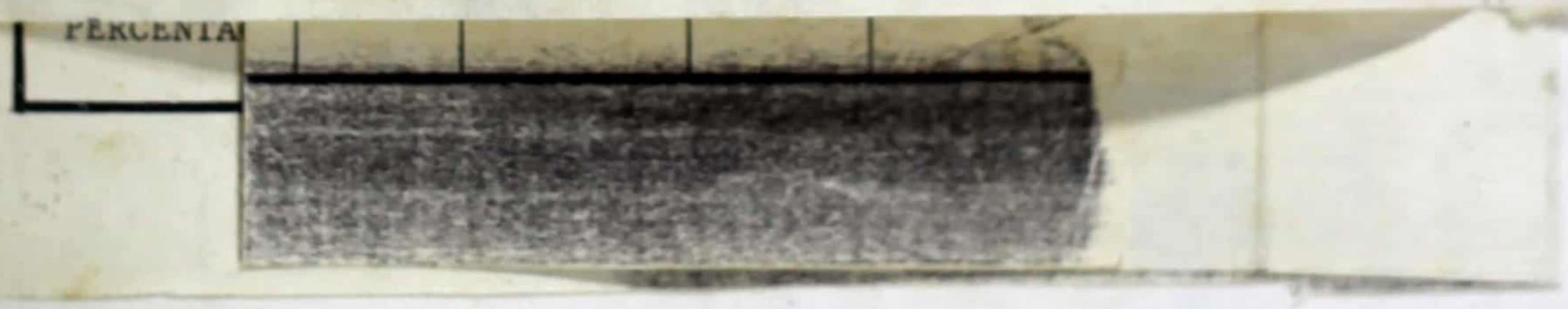

TABLE 9 A TABLE SHOWING THE DISTRIBUTION OF TOXORHYNCHITES S
(APRIL — JUNE 19

PLACES SURVEYED	TYPES OF MICROHABITAT											
	TREE HOLES	LORRY TYRES	OIL TANK	WATER JAR	IRRIGATED CANAL	CRAB HOLE	TIN CANS	ROCK POOL	GROUND POOL	POND	DRAIN	FAULTY SINK
HALLS	209	0	0	8	0	0	5	0	6	0	5	9
SWAMPY AREA	163	0	0	0	0	8	0	0	16	0	0	0
DEPARTMENTS	186	48	9	0	0	0	15	0	7	0	8	0
SENIOR STAFF	287	0	0	0	0	0	12	0	5	0	3	0
BOTANICAL GARDEN	74	15	0	0	0	17	5	13	18	11	0	0
IRRIGATED FARM	0	0	0	10	32	25	0	0	3	3	0	0
ORANGE ORCHARD	7	0	0	0	0	2	0	0	5	10	0	0
MEDICAL SCHOOL	0	21	0	0	0	0	0	0	0	0	0	0
JUNIOR STAFF	165	18	5	20	0	0	28	2	24	16	12	0
TOTAL	1091	102	14	38	32	52	65	15	84	40	28	9
No. of places investigated	7	4	2	3	1	4	5	2	8	4	4	1
PERCENTAGE	69.49	6.49	0.89	2.42	2.03	3.31	4.14	0.96	5,35	2.55	1.78	0.

6.12 Sampling of Mosquito and Toxorhynchites Population in regions Bordering Ashanti

There were no Toxorhynchites in the Tree-holes, water containers nor cocoa-pod husks which were investigated in the regions bordering Ashanti. The mosquito species observed in the tree-holes were Culex (Culex) decens Theobald, Culex (Culex) thalassius Theobald; Aedes (Stegomyia) aegypti Linnaeus, Aedes (Stegomyia) luteocephalus Newstead; but in Ho, Anopheles (Celia) stephensi Theobald were found in some of the tree-holes but not Toxorhynchites.

7.0 DISCUSSION

7.1 Identification of Aedes and other mosquitoes

Although it was not possible to survey all possible breeding places, it was necessary to locate most of the Aedes mosquito sites as accurately as possible so that circumstances favouring Aedes mosquito population may be known.

Thus the survey did not confine itself to the traditional domestic breeding places only, but also took into consideration the problem posed by warehouses, tyre dumps, the installations of modern buildings (Mouchet, 1971).

Of all the mosquitoes identified, only Aedes (Stegomyia) vittatus Bigot and Toxorhynchites brevipalpis Theobald were not found previously in the Ashanti Region. Toxorhynchites was the most widely distributed mosquito found and has a pH range 6-10 in all the habitats investigated. The wide pH range of Toxorhynchites gives it a great advantage in colonizing varied habitats as a predatory agent for Aedes mosquitoes. Although Toxorhynchite density was only 2.3% of the total mosquitoes, it is distributed over a wider area than any other mosquito species and enhances the control of Aedes mosquitoes.

At the University Campus, about 90% of mosquito larvae were collected from tree-holes, all of whose heights ranged between one and 2 metres tall (Plate 3). The most dominant tree species were Poincinia regia Boj (Flambouyant tree); Pentaclethra macrophylla Benth and Albizia zigia Macbride which have almost all the tree-holes in which mosquito larvae were found breeding. One of the most

concentrated areas for mosquito breeding is behind and around the University Hospital where the trees are mainly Poincinia regia Boj. However, very high concentrations of Aedes mosquitoes were also found at the axils of Colocasia spp and Musa spp at the swampy areas (Plate 4) and also in the canals and crab holes of the irrigated farmlands (Plate 5).

The Culex mosquitoes, (Culex decens, Culex tarsalis) were found in all the localities surveyed but were most numerous at Anloga, U.S.T. and Ejisu with U.S.T. registering the highest number (1088). This is probably because of the polluted drains which are favourable breeding grounds for Culex mosquitoes. The pH range for the Culex mosquitoes was 6-8.

Anopheles is found everywhere but dominant at U.S.T. probably because of the ponds, marshy areas and irrigated canals which normally favour the breeding of Anopheles gambiae mosquitoes. The pH range for Anopheles gambiae is $6-7^{+}$

The highest incidence of mosquito population on the campus was in July and the least was in January indicating the influence of rainfall.

In the 4 localities studied, Aedes aegypti (81%) is the most dominant. Again, Toxorhynchites (3.1%), although relatively small, is the most widely distributed.

7.2 Biological Control

The most interesting part of the research work was the discovery for the first time of Toxorhynchites in the tree-holes and other breeding receptacles. They are not only surface swimmers but also able to swim to the bottom of water and even penetrate the mud. This habit not only makes Toxorhynchites an efficient predator, but also serves as a means of escape from its own enemies.

PLATE 4: A SWAMPY AREA AT U.S.T. CAMPUS SHOWING SUITABLE BREEDING PLACES FOR AEDES MOSQUITOES IN TREE HOLES, AXILS OF COLOCASIA ESCULANTUM VIGNE (COCOYAM) AND MUSA SAPIENTUM LINN. (PLANTAIN)

PLATE 5: IRRIGATED FARMLAND ILLUSTRATING CANALS AND CRAB HOLES WHERE AEDES MOSQUITOES BREED.

The duration of Toxorhynchites development was studied under laboratory condition of 26.5°C ± 2°C and Relative Humidity of 68% ± 4.8°C. There were 4 larval instars of relatively longer duration (41.6 days) than Aedes (8.5 days) and this gives it the advantage of predation on Aedes mosquitoes. More of the female Toxorhynchites lived longer than the males and is advantageous for laying more eggs to control Aedes mosquitoes population.

The early first instar larvae of Toxorhynchites had a transparent white body and reddish brown head and siphon. The criteria for determining the larval instars are the moult and width of the head capsules. Mortalities at the first and second larval instars were high probably as a result of competition. The first larval instars sometimes showed cannibalistic behaviour even in the presence of adequate number of prey (Aedes aegypti. They could also not feed on bigger 3rd and 4th instar prey larvae. However, the development of the Toxorhynchites larvae is rapid and the 3rd instar could consume greater number of prey than the earlier instars. There was very little cannibalism as insects reached 3rd and 4th instar stages. The 4th instar was the most aggressive and even killed the prey larvae without eating them. This behaviour usually occurred within 2-3 days before pupation. The average numbers of prey (Aedes aegypti) consumed by a larvae in each stage of development were 8.6, 6.5, 37 and 268 respectively.

The low number of Toxorhynchites encountered (3.1%) is probably to ensure its own survival as one Toxorhynchites could sustain on several hundreds of prey during its development. The size of prey larvae reflects the feeding habit of Toxorhynchites as well as duration of development. For example, observation showed that first and second instars of Toxorhynchites preferred feeding on small size of prey like second instar (Aedes)

but 3rd and 4th instars of Toxorhynchites preferred the bigger size of prey. Besides, the duration of development became shorter after providing appropriate sizes of prey larvae to Toxorhynchites larvae as compared to those feeding only on the 2nd instar prey larvae.

Experiments on feeding preference of Toxorhynchites showed that, the most preferred mosquitoes is Aedes aegypti, as compared with Culex decens and Anopheles gambiae. An analysis of variance between Aedes aegypti, Culex decens and Anopheles gambiae showed a highly significant ($P < 0.01$) preference for Aedes aegypti. (Table 8). However there was no significant difference between the bias for either Culex or Anopheles ($P > 0.05$). The significant preference for Aedes aegypti was probably due to co-evolution.

All the instars of Toxorhynchites show some degree of tolerance (resistance) to starvation but the 4th instar showed the highest level of tolerance to starvation. It was observed that about 10% of the Toxorhynchites larvae pupated before the end of the experiments. Some of the 4th instars could endure 90 to 100 days. In a control experiment where a group of Toxorhynchites larvae were not fed at all throughout the experiment, their life-span ranged from 2-12 days. In another control where the Toxorhynchites larvae were fed throughout the experiment, only 7.5% of the larvae died before the end of the experiment. The other larvae developed to the adult stage eventually.

Should the food supply fail, the Toxorhynchites are able to Survive long periods with little or no sustenance. Schwetz (1930) records survival for 10 weeks without food, and Wiggleworth (1929) mentioned having kept one alive (at 24°C) for 5 months by limiting the food supply. A confirmatory laboratory observation

at U.S.T. showed that 3 Toxorhynchites larvae endured 8 weeks of starvation before pupation.

The larva has the habit of spending most of its time at the surface of the water, its pasture at swimming is not horizontal as Culex (Lutzia) tigripes, but moves with head downwards. On being disturbed, however, it at once seeks the bottom, where it is able to remain for at least 2 or 3 minutes without coming to the top to breathe (Macfie and Ingram, 1922-23).

The survey in the study area shows that Toxorhynchites usually appeared breeding in discarded jars (Plate 6) and domestic jars (Plate 7), discarded tyres (Plate 8) and water container under shade of plants. However, the most preferred habitat was tree-holes (Plate 9). They breed and survive under a wide range of pH and temperature where other mosquitoes are unable to cope. The temperature range of their breeding habitat is 25°C - 32°C, although laboratory observations showed that they survive in water cooled to 20°C with ice blocks. The pH range of their distribution is pH 6-10 ± 0.13 S.D. There is also a varied range of climatological parameters which the Toxorhynchites are able to endure.

Hopkins (1952) stated that because of their predaceous habits, it is unusual to find more than one Toxorhynchites larva unless the breeding place is large (a very large tree-hole or barrel), but observations during the survey at U.S.T. showed that some of the small tree-holes had more than 5 Toxorhynchites larvae while the bigger ones had 10-15 larvae. Some breeding pools had more than 15 Toxorhynchites larvae. There were instances when only Toxorhynchites were found in some tree-holes but no other mosquitoes.

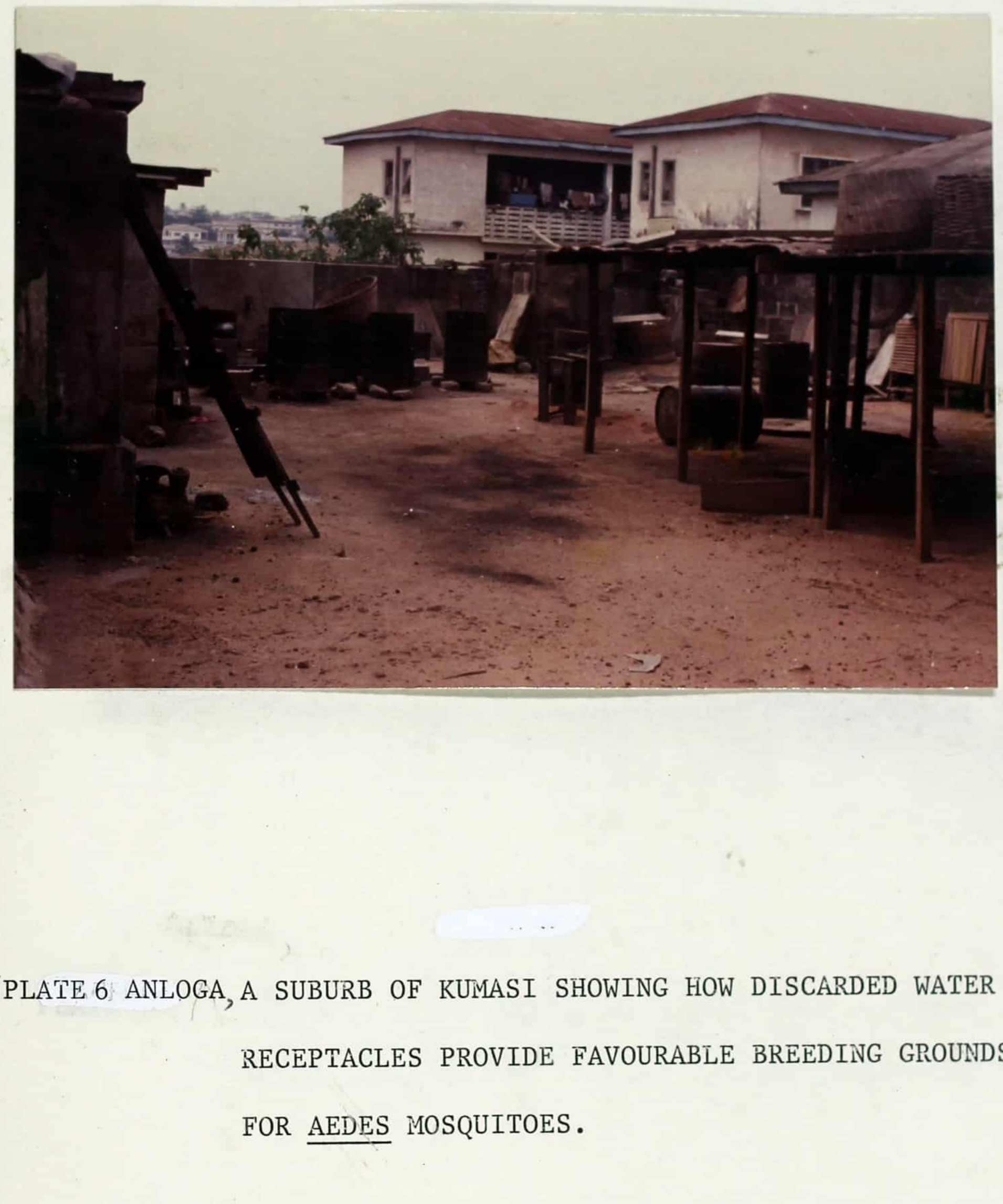

PLATE 6 ANLOGA, A SUBURB OF KUMASI SHOWING HOW DISCARDED WATER RECEPTACLES PROVIDE FAVOURABLE BREEDING GROUNDS FOR AEDES MOSQUITOES.

PLATE 7: LOCAL METHOD OF COLLECTING AND EXPOSING WATER WHICH ENHANCES THE BREEDING OF AEDES MOSQUITOES.

PLATE 8: LORRY TYRES IN THE U.S.T. MEDICAL SCHOOL WHERE AEDES MOSQUITOES BREED.

PLATE 9: A TYPICAL TREE HOLE WHERE AEDES MOSQUITOES AND TOXORHYNCHITES BREED

7.3 Vector Indices

The Biting Rate is highest (0.90-0.96) toward the end of the rainy season (August-October) and least (0.17-0.15) in December-January. The house index has a peak between June (12.5) and August (13.0) when it starts declining till January when there are no rains. The container index is highest in June (5.75) and it starts declining till November (1.79). It rises in December (4.31) and declines in January (4.27). The Breteau index is highest in June (22.25) and declines gradually till November (6.88). It is 10.68 in December, 10.25 in January but in February and March it is 7.75.

The Biting Cycles of Aedes throughout the year shows the period of highest activity between 1400 Hours GMT and 2200 Hours GMT when it starts declining again. The time of highest activity is however between 1700 and 1800 Hours GMT or approximately 1730 Hours GMT (5.30 pm) throughout the year (Fig. 6).

The criteria used to assess the risk of Yellow Fever transmission by Aedes (Stegomyia) aegypti L depend on the values of the following indices: House Index, Container index, Breteau index and the Biting Rate. Areas where the House index exceeds 35, container index exceeds 20 and Breteau index exceeds 50 are considered as high risk areas for Aedes aegypti transmitted Yellow Fever (WHO, 1971). In areas where the Breteau index is between 5 and 50 the density of Aedes aegypti is sufficient to promote an outbreak of Yellow Fever if man is in association with wild vector species of the Stegomyia group. Usually, counts exceeding 2 female Aedes aegypti per man-hour may be taken as indicating a significant man-vector contact for risk of Yellow Fever transmission (WHO, 1971, Agadzi et, al., 1985, Addy et al. 1986). Therefore, comparing the

figure obtained in this study with those stated above, the risk of Yellow Fever outbreak in Ashanti is rather small.

7.4 Climatic Factors

The climatic data for the Regions during outbreaks of Yellow Fever over the past 20 years (Table 1) were compared with those of Ashanti Region. Analysis shows that, out of the 1488 cases from 1963-1983, there were 461 deaths (Agadzi et al, 1984; Addy et al. 1986). Statistical analysis (Table 1) shows that there are significant climatological differences between the areas of Yellow Fever outbreak as compared with that of Ashanti Region. For example, Ashanti Region has a higher Rainfall, and Relative Humidity but lower temperature, and sunshine duration.

Apart from climatological differences, there were also significant differences in vector indices as shown in Table 1. The Biting Rate, House index, Container index and Breteau index of Ashanti Region were statistically lower ($P < 0.05$) than the mean of the other regions.

It has been found that in the Ashanti Region, low Yellow Fever vector index recordings were normal findings (Mouchet 1971 Tumfour, 1985; 1986a, 1986b; Baffoe-Wilmot, 1987). This is a significant and probable reason for the paucity of reported Yellow Fever cases in the Ashanti Region of the country.

There was no significant variation in climatological data in Ashanti between the means of the past 10 years and those of 1987/88 when this study was undertaken. That is, Rainfall, percentage Relative Humidity (at 0600 Hours GMT and 1500 Hours GMT) Temperature (Maximum and minimum) and sunshine were all similar. Therefore the vector indices obtained during this study could be reasonably assumed to be true also for the previous years.

Rainfall and Relative Humidity at 1500 Hours GMT are the main parameters that affect mosquito population growth, probably because of the need for moisture in hatching the eggs and water for completing their life-cycles. Therefore, for effective control measures to be made, the timing should be in the months of June and July, the peak of rainfall when mosquito population is highest.

The Breteau index and Biting rates are the best criteria for determining Yellow Fever transmission and outbreaks. In this study, Akropong had the least indices throughout the year. Anloga had the highest Breteau index and Biting rates. The high indices in Anloga may be the result of too many water containers and breeding grounds for mosquitoes.

The peak of the Biting Rate, which is the best index for determining Yellow Fever virus transmission is found in the month of June, which is the appropriate month for effective control measures to be carried out. Any chemical control methods should take into consideration the appropriate concentration as instructed by WHO, 1974, and WHO, 1986, and should be used as little as possible without interferring with the natural control agents such as Toxorhynchites.

Regional Surveys

Results of tree-hole sampling in Regions bordering the Ashanti shows the absence of Toxorhynchites. However, future work requires a continuous assessment of mosquito sampling for at least a period of 2-3 years to confirm this. In any case, previous research by the National Malaria Service, Ho, aimed at finding the distribution of Anopheles mosquito distribution shows that there were no

Toxorhynchites mosquitoes in the Volta Region (Klu, Nfodzo and Amedume, Personal Communication). Other observation on the survey shows that apart from Aedes and Culex mosquitoes, the Anopheles mosquitoes found in tree-holes in the Region were Anopheles gambiae S.I. and Anopheles (Celia) funestus Theobald.

Similarly, previous work by Chinery (1969) during a two-year larval mosquito survey in Accra)1964-1966) aimed at determining the mosquito species in the city of Accra indicates the absence of Toxorhynchites mosquito in the Greater Accra Region. Rather, a total of 25,317 samples of mosquito larvae collected during the period of September 1964 to August 1966 yielded 24 species of mosquitoes comprising 4 Anopheles, 5 Aedes species and 15 other culicines (Chinery, 1969).

Ingram and Macfie (1924) listed 68 species of mosquitoes occurring within the Accra Municipality but none of which included Toxorhynchites.

A recent mosquito survey by Baffoe-Wilmot (1987) indicates that there has been no trace of Toxorhynchites mosquitoes in the Greater Accra Region, neither in the Brong-Ahafo, Northern and Volta Regions.

Mouchet (1971) carried out a research work on potential Yellow Fever vectors in Ghana with emphasis on Northern and Upper Regions, and his report shows the absence of Toxorhynchites in the Northern and Upper Regions. The mosquitoes identified in the Northern and Upper Regions were: Aedes (Stegomyia) aegypti Linnaeus; Aedes furcifer taylori Edwards; Aedes (Stegomyia) vittatus Bigot; Aedes (Stegomyia) luteocephalus Newstead; Aedes (Stegomyia) metallicus Edwards; Aedes (Stegomyia simpson;, Theobald.

While further studies are needed to confirm the absence or otherwise of Toxorhynchites spp in the other regions of Ghana, this study clearly demonstrates that Toxorhynchites is an effective biological control agent for Aedes mosquito. The predator could therefore be used in Yellow Fever endemic and epidemic areas. However, this should begin with the development of a mass culture technique for the insect and also field trials to evaluate Toxorhynchites' ability as a predator in introduced environments.

8.0 SUMMARY OF FINDINGS

1. A study was undertaken in the Ashanti Region of Ghana to identify various species of mosquitoes which may be found in the Region and to use the information to explain why this Region has persistently escaped Yellow Fever epidemics that have swept through the country since 1900.

2. Several species of the Yellow Fever mosquitoes were encountered and identified. These were: Aedes (Stegomyia) aegypti Linnaeus, Aedes (Stegomyia) africanus Theobald, Aedes (Stegomyia) luteocephalus Newstead, Aedes (Stegomyia) vittatus Bigot. Other mosquitoes were Culex (Culex) decens Theobald, Culex (Culex) thalassius Theobald, Culex (Lutzia) tigripes Grandpre, Anopheles (Celia) gambiae S.I and Toxorhynchites brevipalpis Theobald.

3. Aedes (Stegomyia) vittatus Bigot, and Toxorhynchites spp were not previously identified in the Region.

4. The mean climatological records for the past 10 years (1977-1986) was compared with that of the study period (1987/88) and found to be statistically insignificant ($P > 0.05$).

5. Of all the mosquito species identified, Aedes aegypti was the predominant (81%) and widely distributed in the 3 Districts. This was followed by Aedes vittatus (3.3%) and Toxorhynchites (3.1%). The bulk of other mosquitoes apart from Aedes and Toxorhynchites in all the Districts form 9.5%.

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6. Aedes aegypti and Toxorhynchites were the most widely distributed and occur almost throughout the year.

7. The distribution of mosquitoes was influenced by the pH range and ecological variations such as tree-holes, rock pools, drains and ponds.

8. The highest density of mosquitoes occurred between June and September when about 60.3% of the total insects were collected. With an average number of 16.5% the month of June, was the period of the greatest number of insects, while January with a percentage of 0.2%, recorded the least number of insects.

9. Records of Aedes mosquito indices show that Ejisu has the highest House index while Akropong has the least, a statistical analysis indicated that the difference was significant ($P < 0.05$). The values for U.S.T. and Anloga were very close, and the difference was statistically insignificant ($P > 0.05$).

10. Although container index is highest at U.S.T. and least at Akropong, the difference is not statistically significant ($P > 0.05$). Anloga and Ejisu have close values which are also not statistically different ($P > 0.05$).

11. The least Breteau index was found at Akropong while the highest was at Anloga. The difference is statistically significant ($P < 0.05$). The difference between U.S.T. and Ejisu was insignificant ($P > 0.05$).

Although the Biting Rate is highest at Anloga and the least

in Akropong, they are not statistically significant ($P > 0.05$).

12. The biting rates at the various localities were all below the threshold values for Yellow Fever outbreaks.

13. The biting Rate is highest (0.90 - 0.96) towards the end of the rainy season (August - October) and least (0.17 - 0.15) in December - January.

14. The Biting cycles of Aedes mosquitoes throughout the year shows the period of highest activity between 1400 Hours GMT and 2200 Hours GMT. The exact time of highest activity is 1730 Hours GMT.

15. The study has confirmed the low Yellow Fever vector indices previously recorded in the Ashanti; and therefore a probable reason for the paucity of Yellow Fever cases in the Ashanti region of the country.

16. The most interesting finding of the research work was the discovery and the wide distribution of Toxorhynchites brevipalpis Theobald in the tree-holes and other breeding receptacles in the study areas, for the first time.

17. Laboratory studies shows that, there are 4 larval instars of Toxorhynchites brevipalpis. The egg lasted for about 2.08 - 2.40 days. The first larval instar was 2-3 days, the second was 1-2 days, the third was 2-15 days and the fourth larval instar was 16-43 days. The pupa was 4-6 days and the adult had a range of 20-45 days.

18. Toxorhynchites larvae had relatively longer life-span (41.6 days) than Aedes larvae (8.5 days) and this gives Toxorhynchites the advantage of predation on Aedes mosquitoes.

19. A laboratory experiment on starvation of Toxorhynchites shows that, the first instars lived for 10-25 days. The 2nd instars lived for 4-15 days. The 3rd instars lived for 9-65 days while the 4th instars endured for 20-100 days.

The long endurance of Toxorhynchites gives it an advantage as a predatory agent for Aedes mosquito control.

20. The number of Aedes aegypti larvae (2nd instars) consumed by first instar Toxorhynchites range 6-15. The second instars consumed 4-11. The 3rd instars consumed 10-80 larvae. The fourth instars consumed 185-432.

The large numbers of Aedes mosquitoes consumed by Toxorhynchites shows its biological control capacity.

21. Toxorhynchites prefers Aedes aegypti larvae to Culex decens and Anopheles gambiae as prey. The respective numbers consumed per day by the 4th instar larva of Toxorhynchites were as follows: Aedes aegypti 23.71±7.24; Culex decens 8.91±4.08 and Anopheles gambiae 10.86±3.29.

The feeding preference of Toxorhynchites on Aedes mosquitoes further reveals its predatory capacity in controlling the Yellow Fever vectors.

22. Toxorhynchites species were located in various habitats. The most preferred microhabitat is tree-holes (69.5%), lorry-tyres (6.5%) and the least preferred microhabitat is faulty sink which gave about 0.57%.

23. The pH range of the microhabitats is highest at the Botanical garden (pH 6-10) and mainly in tree-holes (pH 6-7), drains and rock pools (pH 9-10).
The wide pH tolerance of Toxorhynchites gives it the advantage of the wide distribution for the control of other mosquitoes.

24. There were no Toxorhynchites in the tree-holes, water containers nor cocoa-pod husks which were investigated in the other regions of Ghana. The mosquito species observed in the tree-holes were mainly Culex (Culex) decens Theobald; Culex (Culex) thalassius Theobald; Aedes (Stegomyia) aegypti Linnaeus; Aedes (Stegomyia) luteocephalus Newstead; but in Ho, Anopheles (Celia) stephensi Theobald were found in some of the tree-holes but not Toxorhynchites.

9.0 RECOMMENDATIONS

For effective biological control of Aedes mosquitoes, future research work should focus on the following:

1. Development of mass culture techniques of Toxorhynchites.
2. Field assessment of the ability of Toxorhynchites to establish itself in new habitats of Ghana.
3. Study of effects of Toxorhynchites in field on vector mosquitoes.
4. To find out if Toxorhynchites could shift feeding preference to other mosquito species, especially Anopheles gambiae, after many generations, in the laboratory.

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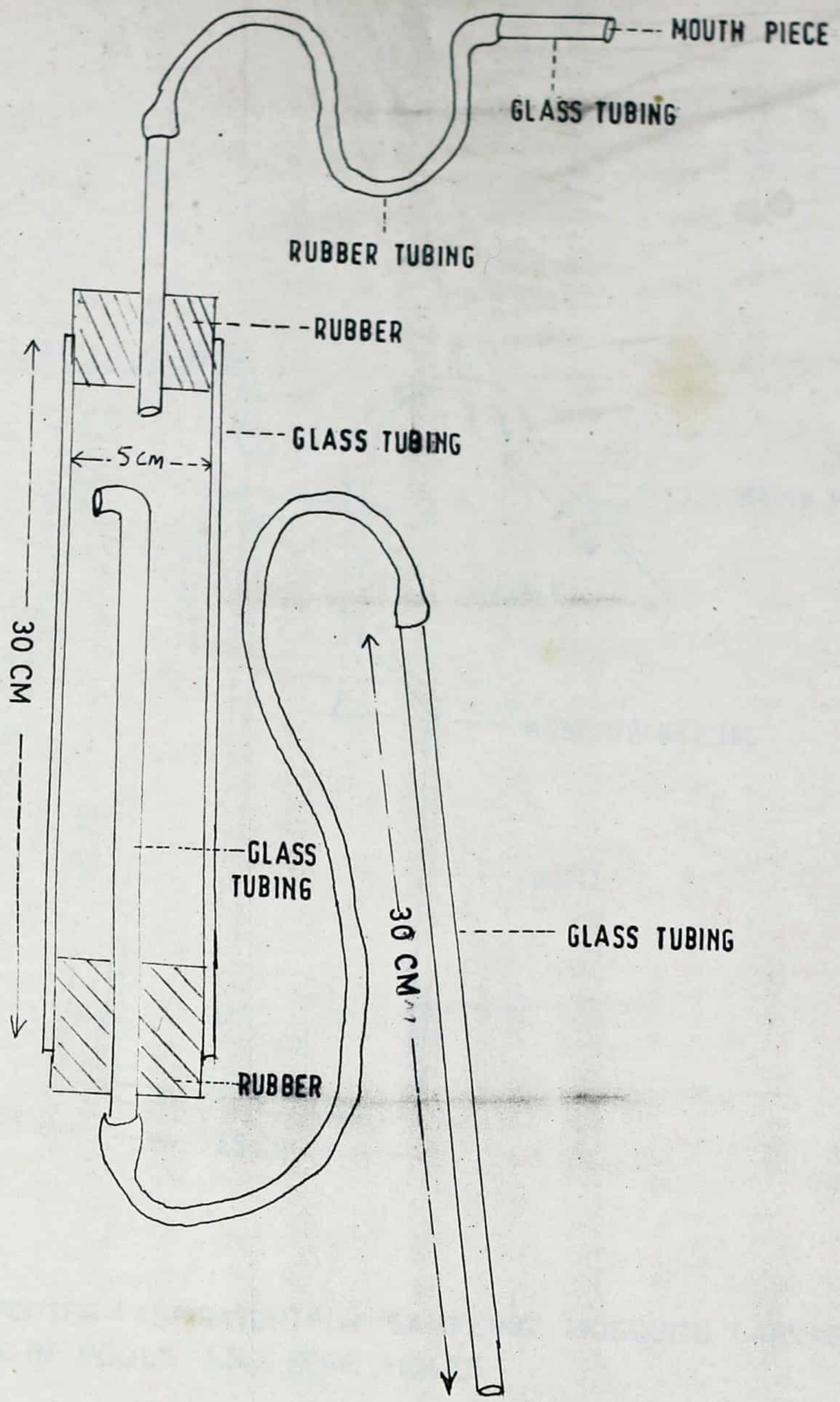
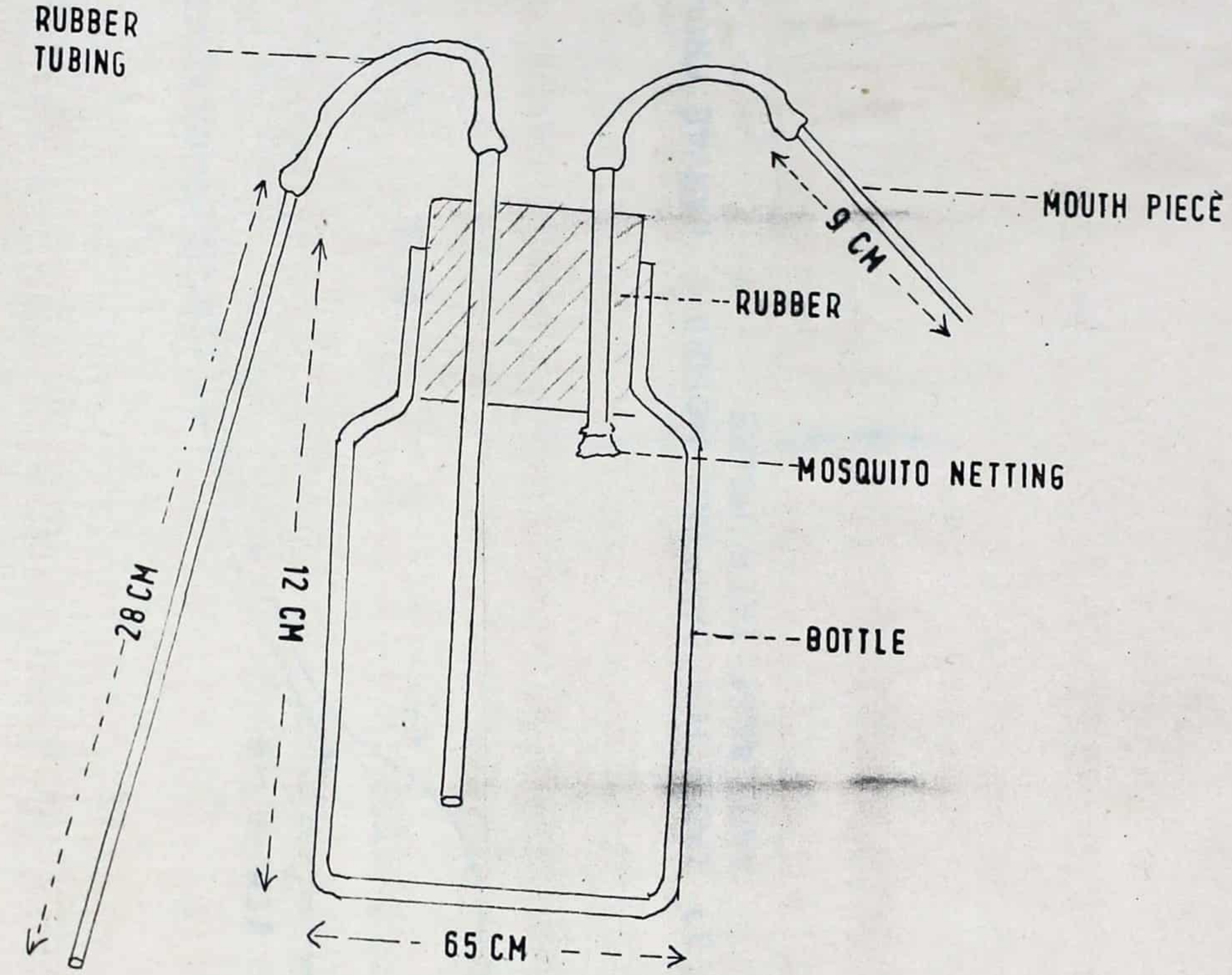
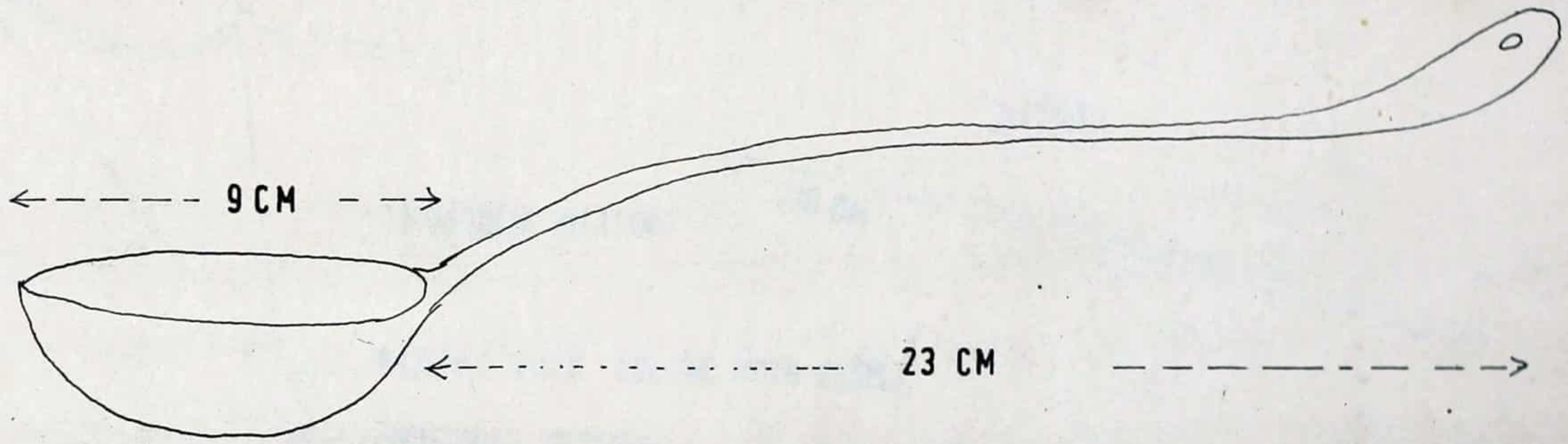


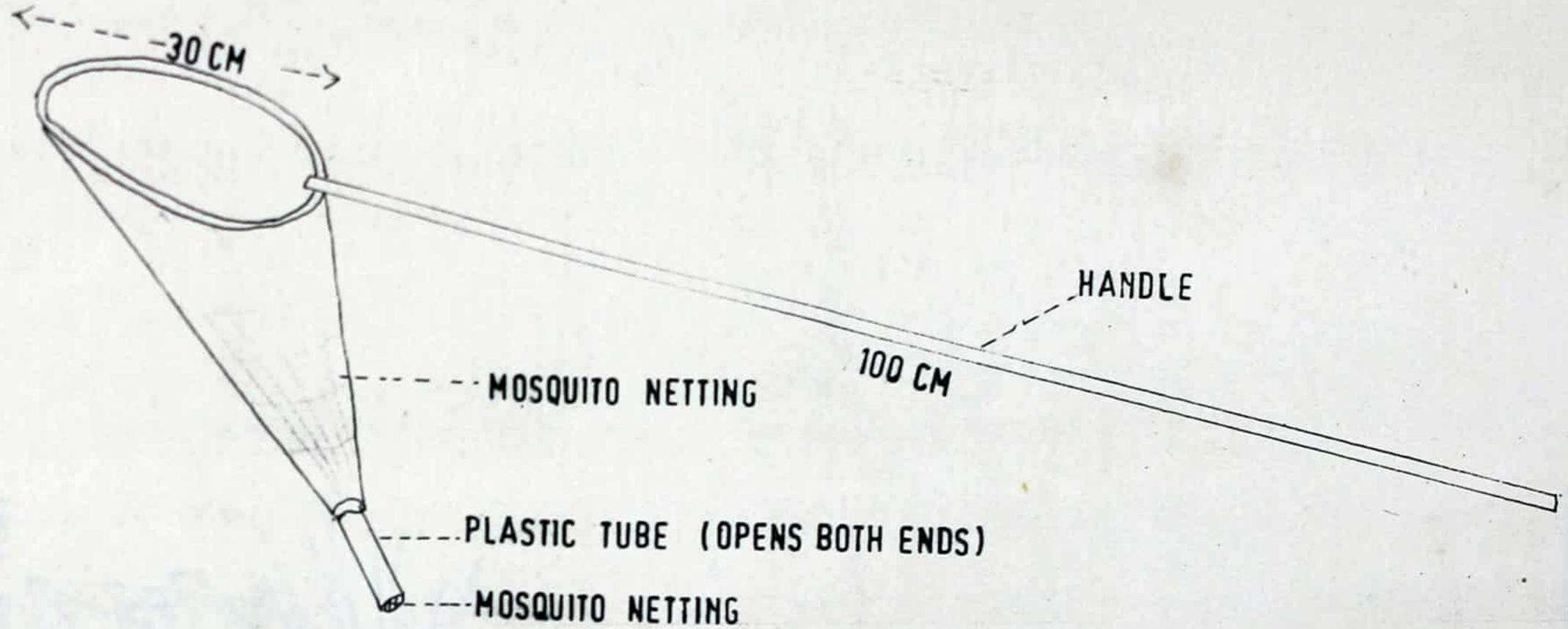
PE DIX fig (1) SIPHON FOR SAMPLING MOSQUITO LARVAE FROM CRAB HOLES, ROCK POOLS AND TREE HOLES



APPENDIX fig(2) POOTER (ASPIRATOR) FOR SAMPLING MOSQUITO LARVAE FROM RAIN POOLS AND TREE HOLES

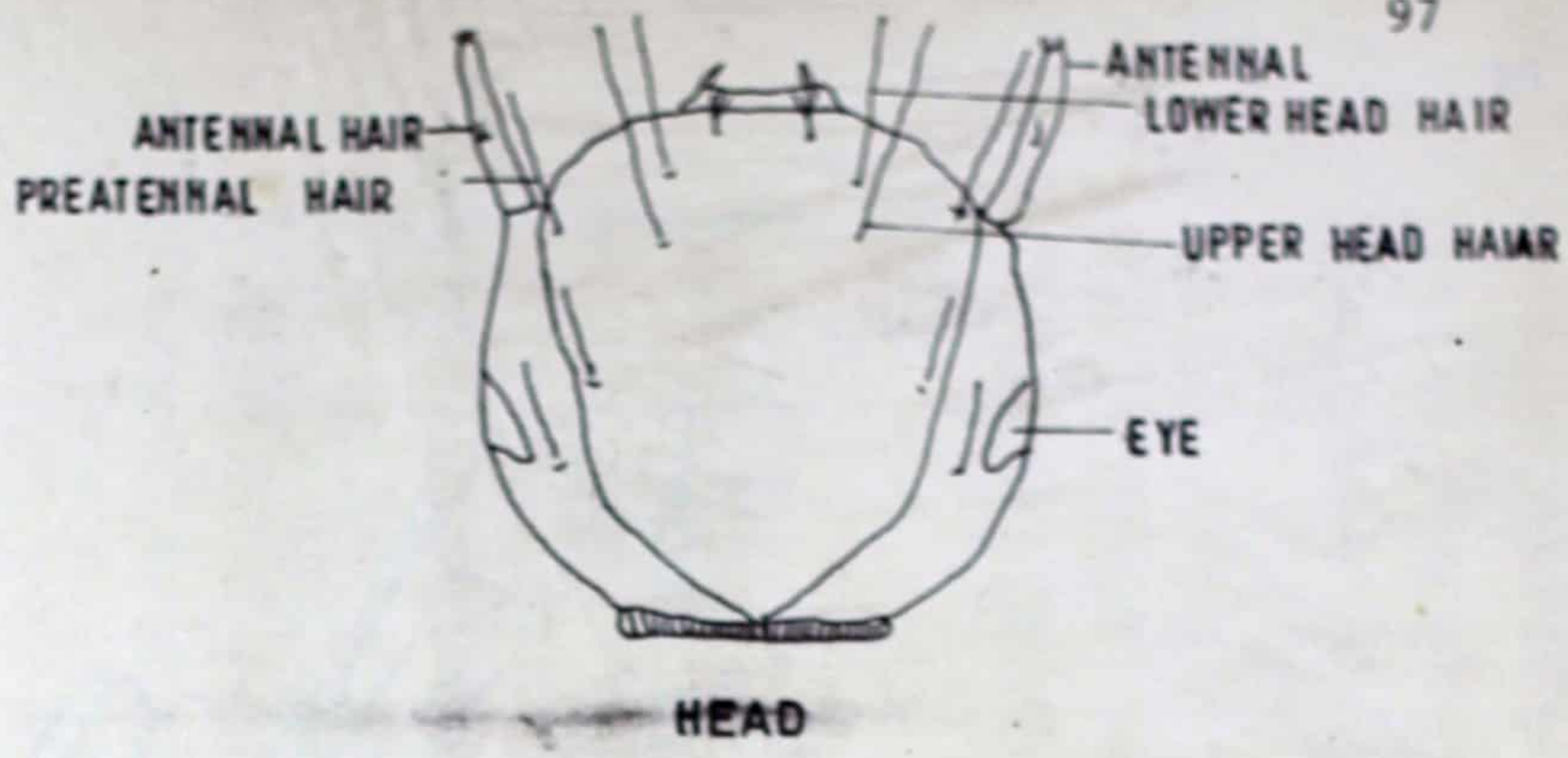


APPENDIX fig(3) LADLE FOR SAMPLING MOSQUITO LARVAE FROM PONDS DRAINS AND LARGE TREE HOLES

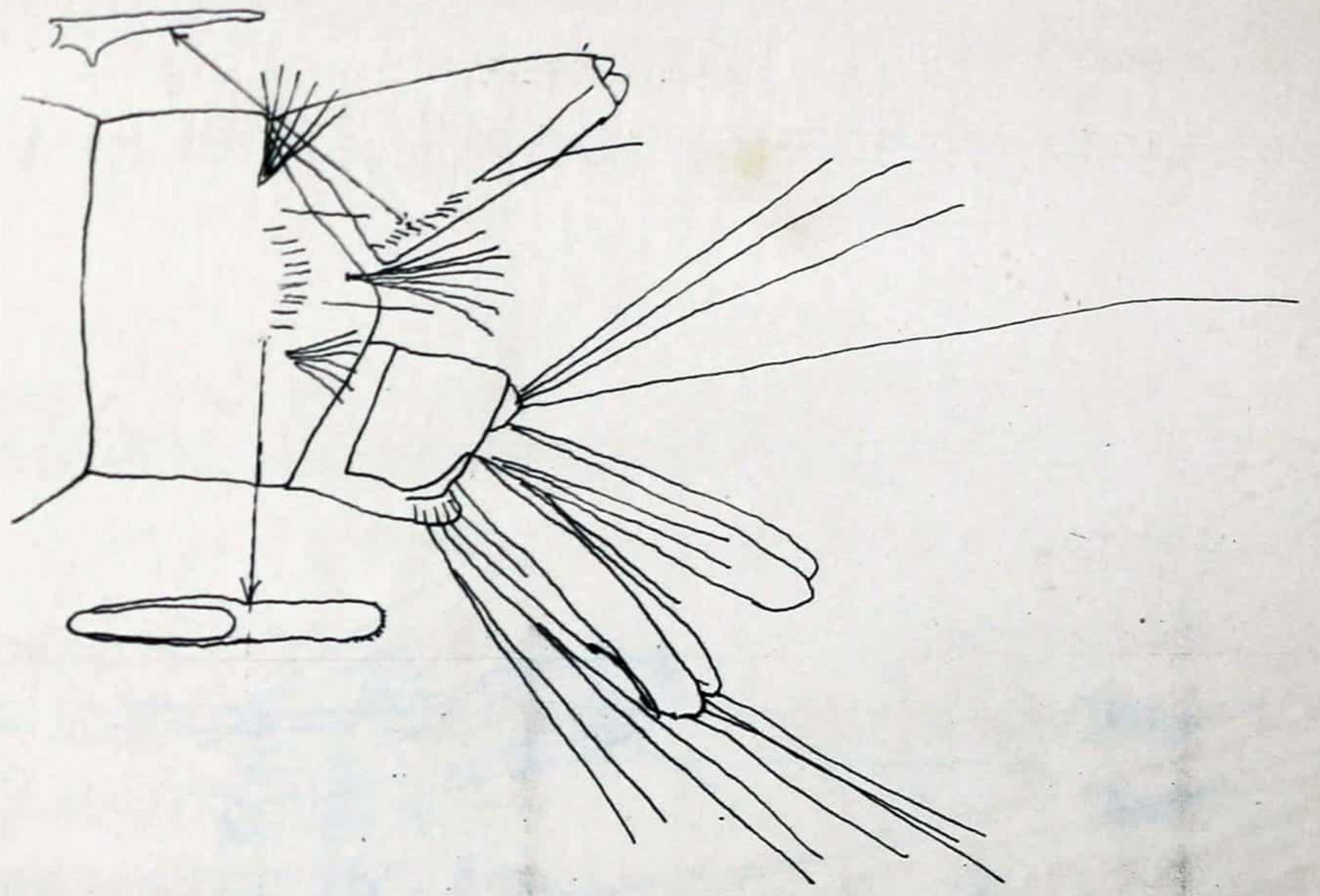


APPENDIX fig(4). SWEEP NET FOR SAMPLING MOSQUITO LARVAE IN PONDS.

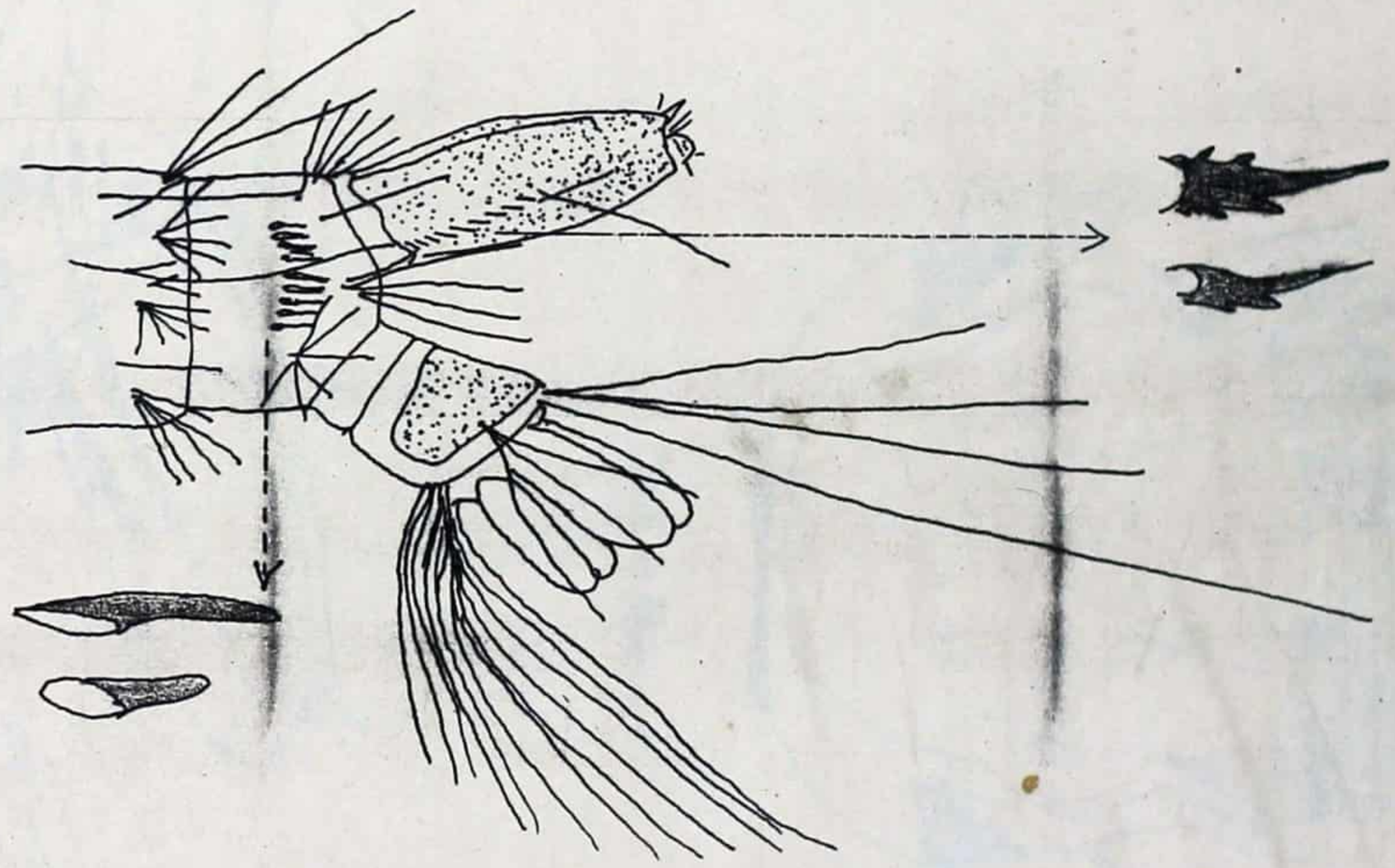
AEDES AEGYPTI LARVA



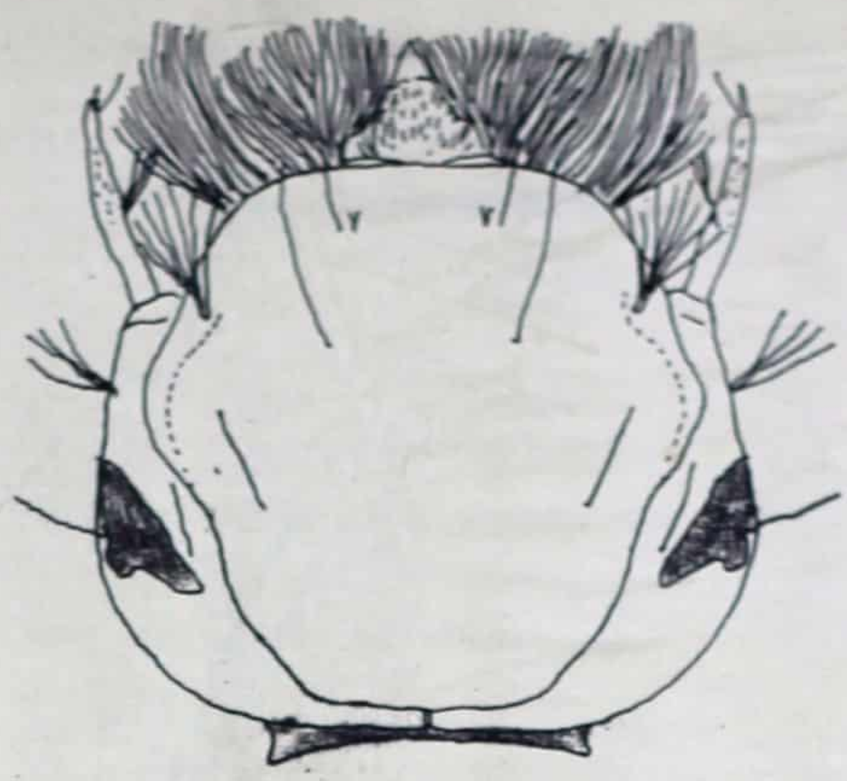
APPENDIX fig(5) AEDES (STEGOMYIA) AEGYPTI LINNAEUS. HEAD AND TERMINAL SEGMENT



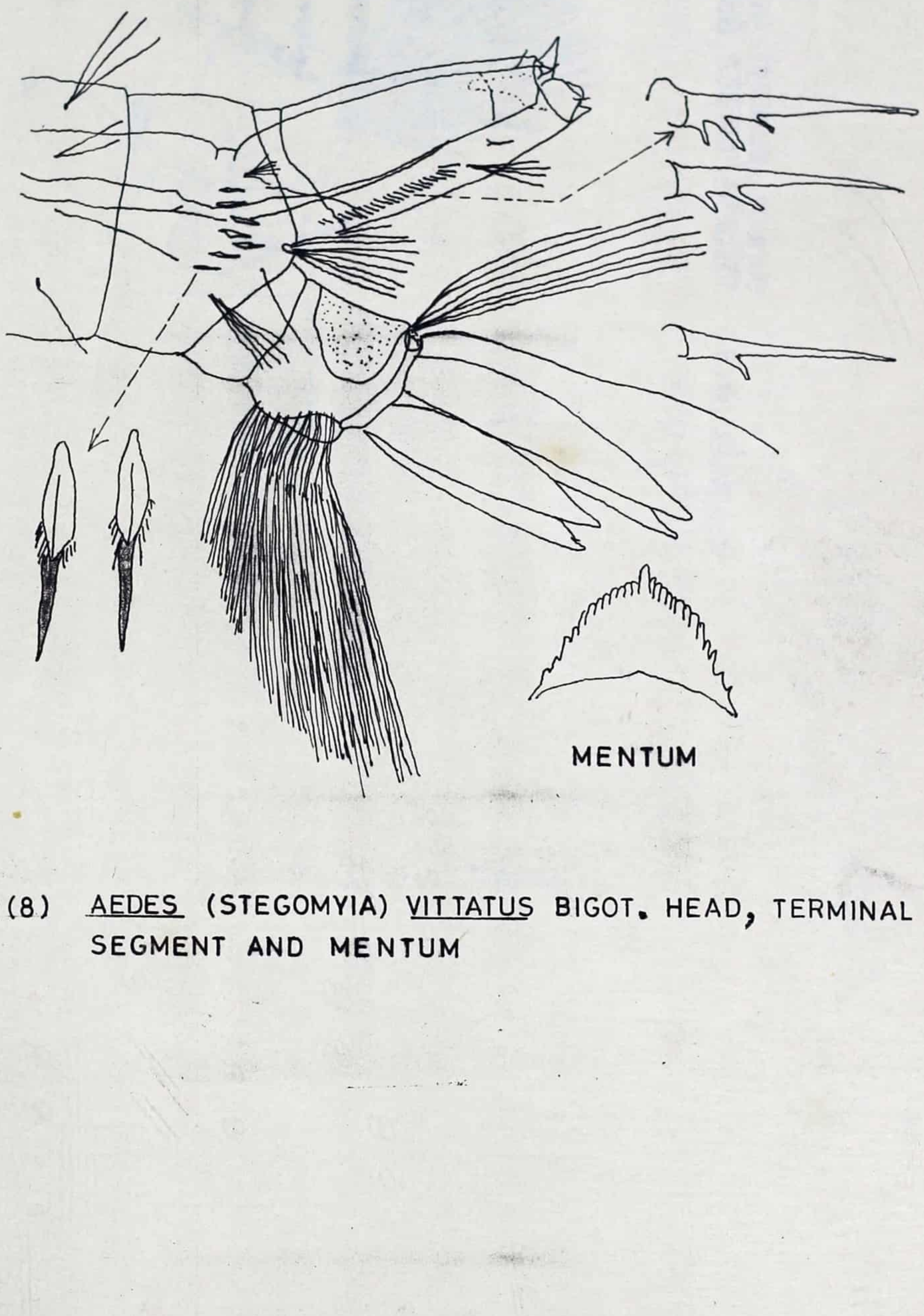
APPENDIX fig (6) AEDES (STEGOMYIA) AFRICANUS THEOBALD.
TERMINAL SEGMENT



APPENDIX fig(7) AEDES (STEGOMYIA) LUTEOCEPHALUS NEWST. TERMINAL SEGMENT.

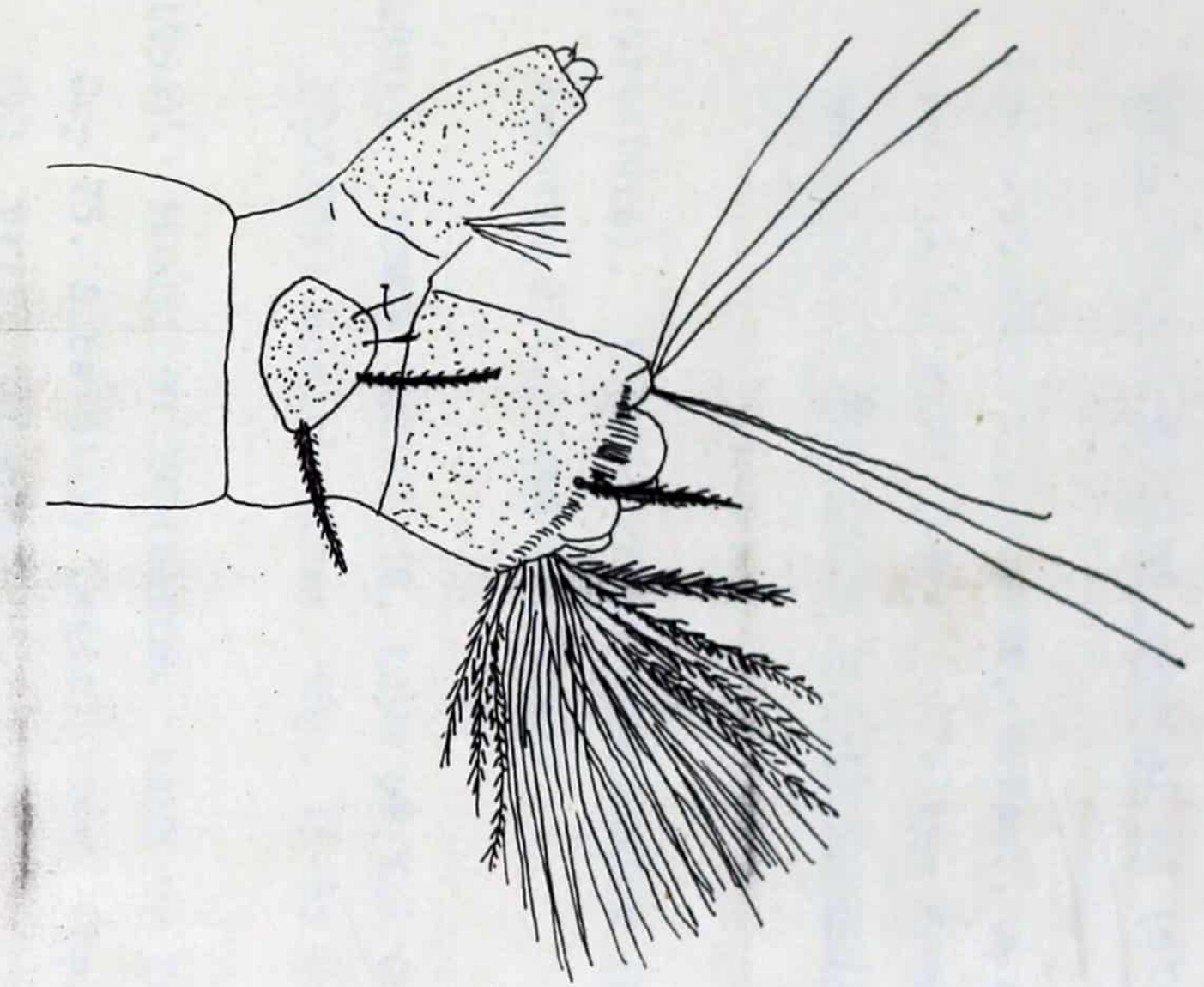


HEAD



MENTUM

APPENDIX fig (8) AEDES (STEGOMYIA) VITTATUS BIGOT. HEAD, TERMINAL SEGMENT AND MENTUM



APPENDIX fig (9) TOXORHYNCHITES BREVIPALPIS THEO VAR CONRADH GRÜNB. TERMINAL SEGMENT

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