ECOLOGY OF MALARIA VECTORS IN RELATION TO AN IRRIGATION SCHEME IN BARINGO DISTRICT, KENYA.

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DECLARATION

I declare that this is my own original research work and all assistance has been duly acknowledged. This work has not been submitted to any other University.

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ABSTRACT

A comparative study of the ecology of mosquito vectors of malaria was carried out in the Perkerra irrigation scheme and the Loboi swamp in Baringo district, Kenya.

The swamp was found to be more productive than the irrigation scheme both in terms of species diversity and the relative abundance of individual mosquito species. Seventeen mosquito species were collected and identified and all of these were found breeding in the swamp, while only 5 species were breeding in the irrigation scheme. Two known malaria vectors, Anopheles gambiae Giles sensu lato and Anopheles funestus Giles were among the 17 species identified. The two were collected in almost equal numbers in the swamp area (1466 and 1475 respectively, between January and December, 1986). A.funestus was very scanty in the irrigation scheme, with only 28 collected as against 845 A.gambiae, between January and December, 1986.

A.gambiae peak population was recorded during the rainy season, April to July in the swamp and during the cool dry period following the rains, July - September, in the irrigation area. For A.funestus, the peak numbers occurred between the end of the cool dry period and the beginning of the dry season (August - November).

Rainfall was the most important factor affecting seasonal population fluctuations at the swamp. However, at the irrigation scheme, other factors, especially farming and irrigation practices, were observed to affect the vector population significantly.

Larval survivorship was similar in both types of habitat and predation seemed to be the major mortality factor during larval development. Adult survivorship was, however, significantly higher in the irrigation scheme than in the swamp. The higher survival rate at Perkerra was probably due to factors related to irrigation, in particular the provision of cooler and more humid microclimates by growing crops and shade trees in the irrigated areas, especially during the long dry season.

The two vector species were strongly endophilic but a degree of exophily was evident among the gravid females, which was stronger in A.gambiae (33%) than in A.funestus (15%). A. gambiae also showed a higher preference for human blood, with a human blood index of 88.6% than A. funestus with an index of 58.8%.

Malaria accounted for 56% of all sicknesses treated annually in the area. Transmission occurred throughout the year with the peak between April and September. Crude inoculation rates were four times higher in A.gambiae than in A.funestus, indicating that the former was the more efficient and important vector in the area.

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GENERAL INTRODUCTION

Malaria has been and still is the most important parasitic disease in the tropics. It has been estimated by the World Health Organization (W.H.O, 1985, 1987) that 365 million people, nearly one-twelfth of the world's population, were living in areas, mostly in Africa, where malaria was still highly endemic and where no specific anti-malaria measures were being applied. A further 2217 million people, 46% of the world's population, were living in areas where malaria was endemic but where control measures have reduced its level of endemicity.

In areas other than tropical Africa, the incidence of the disease is currently estimated at 20 million cases a year. In Africa south of the Sahara about 200 million people are believed to be chronically infected and of these, about one third suffer acute manifestations of the disease in the course of the year. The consequences of this high morbidity on socio-economic activities are devastating. There exists a vicious circle of diseases (eg malaria) and poverty in most of the endemic third world countries. Productivity is low because many workers are sick; reduced productivity results in reduced standards of living which in the long run predisposes people to sickness (Brown, 1973; W.H.O, 1980).

The malaria eradication campaign launched by the World Health Organization in 1955 (Bruce-Chwatt, 1985)

eradicated or drastically reduced the disease in many parts of the world, notably the U.S.A., Europe, parts of Asia, and South America. This campaign could not, however be extended to Africa because of the enormity of the malaria problem in Africa. Coupled with this was an acute shortage of locally trained manpower, inadequate transport and communication system. Since 1969, the W.H.O has changed its strategy on malaria from global eradication to control (Bruce-Chwatt, 1985). To this end, more emphasis is being laid on increased research into various aspects of the disease and its vectors especially, with regard to how they are related to local environmental conditions.

Over the years, numerous studies in many parts of the world have provided an impressive amount of knowledge on mosquitoes and malaria. In fact, there is an erroneous impression among some people, that knowledge on the behaviour and ecology of these insects is now exhaustive. This is, however, not true. The individual species of mosquito vectors of malaria have distinctive habits and special relationships with their environment. These distinctive habits and interactions with the environment, vary from one locality to another, even for the same species, and are crucial in defining the epidemiology of the disease in any given locality (Gillies and De Meillon, 1968; Muirhead-Thomson, 1982). The failure to recognize this fact, and the consequent attempt to base control measures in one locality upon entomological and ecological data collected

in another place has been largely responsible for poor results in most anti-mosquito campaigns (Muirhead-Thomson, 1982).

Environmental manipulation can be an effective method of mosquito control under certain conditions (Waddy, 1975; Paterson, 1975; Bruce-Chwatt, 1985). The breeding habits and habitats in that locality of the vector species must, however, be thoroughly understood before the environment can be modified to render it unsuitable for the vector. Failure to do this may lead to undesired results. For example, clearing of vegetations from the breeding sites in an area where an open-water breeder is the major vector but co-exists with a non-vector which breeds in vegetation-covered water, will only lead to increased transmission (Waddy, 1975). The means and methods of control must therefore always take account of local epidemiological and ecological situation. The better we understand the epidemiological conditions of local transmissions the more correct will be our choice of control measures and the more successful will be the resultsobtained (Holstein, 1954; Deklemishev, 1962; W.H.O., 1967; Muirhead-Thomson, 1982). In other words, every geographical unit with distinctive climatic and topographical features should be studied to ascertain the characteristics of the main malaria vectors and the environmental factors that control them before any control measures can be embarked upon with a reasonable expectation of success.

A major contributory factor to the problems of mosquito control in recent years has been the upsurge in the construc-

tion of irrigation schemes, dams, fish ponds etc. These projects which are indispensable for modern agriculture and water management, usually bring about profound changes in the physical and biological environments of the areas concerned. One of the most important aspects of these changes is the escalation of disease transmission by vector organisms whose development are highly favoured by the new environment (W.H.O., 1967; Simpson, 1975).

Mosquito studies should be started prior to construction of any large dam project so that forcasts based on their results can be incorporated into the overall plan (Paterson, 1975). Unfortunately, due mostly to over-riding short-term political and economic considerations, and sometimes to acute shortage of qualified manpower, this essential requirement never gets the serious attention it deserves. Consequently whenever irrigation has been carried out on a large scale, it has been followed by profound changes in mosquito population and often in the incidence of mosquito-borne diseases. Sometimes, the health problems that arise from such extensive modification of the environment, outweigh the economic gains and cause untold damage to the health and well-being of the people (Farid, 1975; Paterson, 1975; Simpson, 1975).

There is therefore an urgent need to study the existing irrigation schemes in relation to mosquito breeding and malaria transmission. In Kenya, this type of study was conducted at the Ahero rice irrigation scheme near Kisumu

(Curtees, 1970 b, 1975; Simpson, 1975; Chandler, 1976; Highton et al., 1979). No studies have been done on the impact of irrigation on mosquito breeding in any other irrigation scheme in the country, including the Perkerra irrigation scheme at Mariget.

In 1984, some attempts were made by the Ministry of Health to control mosquitoes in the Loboi Swamp areas of Mariget (Ngindu, pers. comm.). Parts of the swamp were treated with high solvent (H.S) antimalarial oils and houses were sprayed 2 or 3 times with fenitrothion (organophosphate) over a nine-month period. Since there was no proper pre-spray study, both epidemiological and entomological data were scanty and unreliable. There was no clear picture of seasonal prevalence of malaria in the population or of seasonal changes in densities of the anopheline vectors. It was therefore impossible to determine whether or not the timing and frequency of spraying were suitable and adequate. As entomological baseline data were lacking, it was impossible to evaluate the impact of the exercise. The attempt ended without any real achievement.

The basis of the present project was to undertake a comparative study of the ecology of malaria vectors in the Perkerra irrigation scheme and the Loboi swamp, both in Mariget division of Baringo district, Kenya (Fig 1). The investigation focused on some aspects of the complex interactions between malaria parasites, their vectors and human hosts on the one hand, and their physical and biological environments (natural and man-made) on the other.

Objectives.

1. To study the species diversity, relative abundance and seasonal population changes at both the Perkerra irrigation scheme and the Lobo I swamp

2. To determine how species diversity and relative abundance are affected by the following environmental factors:

(i) Rainfall

(ii) Temperature

(iii) Relative Humidity

(iv) Windspeed

3. To compare the age composition and survivorship of the pre-imaginal and adult populations in the two habitats, Lobot swamp and Perkerra irrigation scheme.

4. To study the behaviour of the major vector species with respect to feeding, resting, and host preferences.

5. To assess infection rates in both man and mosquitoes and to relate vector behaviour to malaria transmission.

6. To assess the impact of irrigation on mosquito breeding by relating fluctuations in mosquito

populations to changes in irrigation practices.

These investigations were conducted simultaneously in a natural mosquito habitat (Loboi swamp) and a man-made habitat (Perkerra irrigation) so as to highlight the modifications to the natural environment brought about by the introduction of irrigation. The effects of these modifications on mosquito breeding and malaria transmission were assessed. Malaria is a serious problem in the Baringo area and there was an urgent need for this type of study in order to provide the baseline data upon which future control measures could be reliably based. It is therefore hoped that the results of this work would be of benefit in the planning and execution of a cost-effective malaria control programme in the Marigat area of Baringo district Kenya.

CHAPTER 1

REVIEW OF LITERATURE

1.1 Species Composition and Distribution

The species composition and distribution of malaria vectors in most parts of Africa have been well documented. In Kenya, Symes (1928, 1931, a, b, 1936, 1940) worked on various aspects of malaria transmission and vector biology in different parts of the country. He established that Anopheles gambiae Giles species complex and Anopheles funestus Giles were the major vectors in this part of East Africa. Studies on mosquito distribution in Kenya have been reported by other workers (Evans, 1936; Evans and Garnham, 1936; Haddow, 1942; Muirhead-Thomson, 1951 a; Service, 1970 a, b; White, 1972; Chandler, 1975; Highton et al., 1979; Mosha and Mutero, 1982; Mosha and Subra, 1982; Mutero, 1985). Two sibling species of the gabiae complex, A. gambiae sensu stricto Giles and A. arabiensis Patton are the most predominant and the most important transmitters of malaria in Kenya, followed by A. merus Donitz (along the coast) and funestus. A. gambiae s.s. predominates in semi-arid and savanna areas (Service, 1970 a; White, 1972; Mosha and Subra, 1982). In the Kisumu area, where these two species are sympatric. A. gambiae out-numbered A. arabiensis inside houses towards the end of the cool

dry season (Sept-Nov) but a reversed situation occurred during the hot dry weather following the short rains, between December and February (White et al. 1972). Service (1973) found A. gambiae s.s. as the dominant species in the same area where White (1972) had worked between November and December. This implies that the populations of these two are not static but are most probably related to rainfall patterns.

Along the east coast of Kenya the salt-water breeding A. merus is the dominant species (Muirhead-Thomson, 1951 a; Iyengar, 1962; Paterson, 1964 b; Mutero et al., 1984; Rogo et al., 1985). In a survey of the geographical distribution and chromosomal polymorphic inversion of the Anopheles gambiae complex sibling species in Kenya, Mosha and Subra (1982) found that A. merus constituted 99% of the population in the coastal shoreline areas of Jimbo and Mombasa. A. gambiae s.s. predominated in the coastal hinterlands of Mishu, Mashehemi and Garashi (100% in May-June and 56.5% in April), although both species are sympatric at most times of the year. A. gambiae s.s. also predominated in Kisumu (lake Victoria basin) area where it is sympatric with both A. arabiensis and A. funestus. A. arabiensis predominated in the Tana River basin, Tavata Savanna and Mwea highland areas, constituting 98 - 100% of catches between May and July (Mosha and Subra, 1982).

In addition to these well-known vectors of malaria, ther are other Anopheles mosquitoes which are important vectors in other parts of the world but whose importance in Kenya is doubtful. These include Anopheles pharoensis Theobald. This species was found [illegible]

distributed in Trans-Nzoia and Kitale areas by Symes (1931 a,b,); in Kisum and other parts of the lake Victoria basin by Haddow (1942), Chandler and Highton (1975), Chandler (1976); and in Malindi, Mombasa and Ganda areas of the Coast (Van Someren et al. 1955). A. pharoensis is a well known vector of malaria in Egypt (MadWar, 1936: Barber and Kice, 1937: Farid, 1975) but in tropical Africa it seems at best a feeble vector and of negligible inportance compared to gambiae and funestus (Garnham, 1945; Giles and De Meillon, 1968). Another species in this group is Anopheles coustani Larvern. This group includes variaties coustani, ziemmanni and tenebrosus. They have been found in large numbers in Kisumu (Haddow, 1942: Chandler and Highton, 1975: Chandler, 1976) and parts of the Coast (Van Someren et al, 1955). They are also of negligible importance as vectors of malaria in Kenya.

Climatic factors affect the survival and fecundity of adult mosquitoes and are therefore important in determining their numbers and seasonal distributions. The most important factors in this respect are temperature and relative humidity (Muirnead-Thomson, 1951 b, 1982: Bruce-Chwatt, 1985). The optimum temperature for activity for most Anopheles species in the tropics is 25-32°C. Activity is increased greatly at 35-37°C but drops rapidly above 38°C. Most mosquitoes die if exposed to this temperature for 5-10 minutes (Muirhead-Thomson 1951 b). Mosquitoes avoid unfavourable temperatures by their resting habits. Muirhead-Thomson (1951 b) found that the temperature of mud huts favoured by Anopheles

minimus Theobald in India as resting sites was 20c lower than the outside air temperature during the cold season. In Kenya, Haddow (1942) also found a difference of about. $3^{O}C$ between the mud huts used by A.gambiae and A.funestus as resting sites and the outside temperatures.

Anopheles mosquitoes favour high relative humidity, 70-90%) and the mean relative humidity of preferred resting sites are usually higher than the outside relative humidity by 10-40% (Haddow 1942; Muirhead-Thomson 1951). Outdoor resting mosquitoes choose heavily shaded sites to ensure favourable temperatures and humidities. Such sites include animal burrows, termite mounds, thick vegetations, wells etc.(Bruce-Chwatt 1985).

Rainfall, by influencing temperature and relative humidity, has an indirect effect on the survival of mosquitoes. Thus most species of Anohpeles reach their peak numbers during the rainy season not only because of increased longevity of the adults (Gillies and De Meillon, 1968; Bruce-Chwatt, 1985). In large bodies of water subject to flooding during heavy rains, peak numbers are attained a few months after the end of the rains when the water level begins to fall (Dunkeen and Omer, 1986, Snow et al., 1987. Winds assist the dispersal of mosquitoes beyond their normal flight limits but very strong winds can also disturb flight and prevent egg-laying (Bruce-Chwatt, 1985).

1.2 Larval Ecology

Numerous studies of the larval breeding sites of A gambiae s.l. have been made throughout the areas of its distribution range. In most of these areas A. gambiae are found to breed in shallow, open, sunlit pools originating from borrow-pits, drains, brick-pits, car tracks and hoof-prints etc. They also breed in pools resulting from over-flow of rivers, pools left by receeding river, rain water collecting in natural depressions etc. (Muirhead-Thomson, 1948; Holstein, 1954; Gillies and De Meillon, 1968). Rice fields constitute another prolific source of A. gambiae s.l. (Gillies and De Meillon, 1968; Highton et al., 1979; Surtees, 1970 b; 1975; Mogi et al., 1986). In general they are most productive of mosquitoes when they are recently flooded and the rice is low. Later on when the rice is fully grown, breeding of A. gambiae is at a lower level and confined to the margins of the field.

However, open, sunlit waters are by no means the only ones in which A. gambiae can breed. Holstein (1954) in Upper Volta found them breeding in pools and ponds covered with vegetation as well as in grassy swamps. A. gambiae also breed in tree holes (Macfie and Ingram, 1923), and in the stumps of banana trees (Garnham, 1929). According to Holstein (1954) such

unusual places are important. They must be taken into account in the course of an anti-malaria compaign directed against the larval instars since they constitute foci of anopheline development. A.gambiae has not been known, however to breed in fast running water or in very alkaline or polluted water (Symes, 1940,1941).

The introduction and establishment of A.gambiae in any place is closely bound up with human activity. Thus the increase in the incidence of malaria in a locality or region is often directly correlated with intensive development of agriculture or simply, with an increase in the human population for one reason or another (Holstein, 1954; Youdeowei and Service, 1983). There are two types of anopheline breeding places created by human activities, (a) small amounts of water collecting in empty tins, barrels, coconut husks, cement tanks etc. around human habitations and (b) large bodies of water such as canals, irrigations, dams, etc. created by large public works (Clegg and Garlick, 1980; Youdeowei and Service,1983).

A. funestus breeds characteristically in bodies of clear water that are large and more or less semi-permanet,e.g. swamps, weedy sides of streams, seepages, etc. (Gillies and De Meillon,). According to these authors the important ecological feature is that of emergent vegetation including short grasses with very little shading of the water surface or tall grasses of trailling vegetation with greater degree

degree of shade. Growing rice provides similar protection. Grainger (1947) in Kenya found that A.funestus breeds prolifically in the third month after planting and that densities were lower if irrigation was intermittent rather than continuous. In ponds with dense marginal vegetation and extensive areas of floating plants, breeding was confined to the former zone. It seems that an important ecological factor is the provision of shelter from predators (Gillies and De Meillon, 1968).

Some workers have, however, found the species breeding in some rather unusual habitats under certain conditions. For example, Symes (1936) describes a study in which he found A. funestus to be breeding consistently in wells and domestic water containers of all kinds in Malindi near Mombasa. In Pemba island, Gillies and De Meillon (1968) found A.funestus breeding in a deeply sunken limestone stream, completely covered overhead with bushes, the water itself devoid of vegetation and with little detritus. This shows that where the range of available sites is restricted, A.funestus is capable of utilizing rather different waters from those normally colonized.

Jepson et al. (1947) stated that temperature is the chief factor controlling Anopheles breeding under natural conditions. For A.gambiae the temperature range is 16-43^{0}C, with the optimum range of 30-34^{0}C. For A.funestus the limits are 16^{0}C and 40^{0}C, and the optimum range is 25-27^{0}C (Symes, 1939; Jepson

et al, 1947). Haddow (1943) studied the effects of temperature and light on the larval habitats of A.gambiae and A.funestus. He found that vegetation had a profound insulating effect on temperature. The range in the grassy pools favoured by A. gambiae. He concluded that not only do the breeding waters of A.gambiae reach higher temperatures than those of such species as A.funestus, A. counstani, and A. pharoensis but they also undergo much greater temperature fluctuations. Wolstein (1954) collected A.gambiae larvae and pupae in shallow excavated pools at Wokry (Sudan) with temperatures between 40.5°C and 41.8°C.

A.gambiae is highly intolerant of gross pollution of either vegetation or animal origin. Hopkins (1933) showed that it can be controlled by the addition of cut grass to the larval breeding sites. According to Gillies and De Meillon (1968) Hancook had achieved the same results in 1930 by adding town refuse to the larval sites. Goma (1960) observed that where swamps had been altered by either cutting or burning of papyrus the burnt habitat produced very few anopheline mosquitoes. Water with suspended colloidal matter such as is seen in brick pits seems particularly favourable to A.gambiae (MCCrae, 1984).

Anopheles funestus shows little tolerance to saline water and in nature is never found in brackish pools (Gillies and De Meillon, 1968, Mosha and Mutero, 1982). Anopheles gambiae also has little tolerance of saline water (except of course the salt-water members of the complex). This difference has

been exploited to distinguish the salt water breeders A.merus and A.melas Theobald from the fresh-water breeders A.gambiae s.s. and A.arabiensis (Ribanda, 1944; Muirhead-Thomson 1951 a, 1982; Mosha and Mutero, 1982; Rogo et al, 1985). Goma (1960 b) investigated the productivity of baricus mosquito breeding sites in swamps in Uganda. Six chemical factors - pH, potassium (K^+), sodium (Na^+), absorbed oxygen, free and saline ammonia and albuminoid ammonia-were studies. Only the quantity of soluble organic matter, indicated by absorbed oxygen and albuminoid ammonia showed any relation to productivity, the least productive habitat containing smallest amount of organic matter.

1.3 Mortality and survivorship of Mosquitoes

1.3.1. Mortality and survivorship of Larvae

Mortality in the immature stages of the mosquito can be caused by a variety of factors - adverse climatic conditions, limited food supply, competition, parasites and pathogens etc. Predation is probably the most important limiting factor (service 1970 b). In certain habitats such as large collections of permanent water and wells, the importance of predation is recognised (Christie, 1958, 1959; Gillies and De Meillon, 1968 Mogi et al., 1984, 1986). White and Rosen (1973) studies the ecology of A.gambiae species A and B in the savanna areas of Nigeria. Random collections of the plentiful fauna in some A.gambiae breeding sites yielded

larvae of Cordullidae (Odonata), Culex pipiens Grandpre and Charmoy and Dytiscidae (Coleoptera) that devoured numerous mosquito larvae after hunting them down efficiently in laboratory bowls. Among the pathogens they found were Vorticella sp (protozoa) which attached themselves by stalk to various parts of the cuticle of A. gambiae larvae. They also found numerous cases of infection with protzoa of the genus Thelchania (Microsporida) and with the fungus Coelomomyces.

Service (1973) studied mortalities of the larvae of A. gambiae complex in ponds, ditches and pools in the Kano plains of Kenya. He recorded an overall mortality of 96% among immature stages in ponds at Rabour and Chiga villages and 100% mortality for larvae in ditches at Chiga. These mortalities were due to heavy infection with Coelomomyces and to predators. Among predators incriminated by precipitin tests were spiders, ants, Coleoptera and amphibians (tadpoles).

Mogi et al, (1984,1986) found that mortality attributable to aquatic predators of Anopheles peditaeniatus and Anopheles siniensis in the Philippines and Thailand rice fields varied from 19 to 54% and was positively correlated to the abundance of aquatic predators. Surface predators were a minor mortality factor (0-10%). The major predators included Dytiscidae, Hydrophilidae, (Coleoptera), Nepidae, Veliidae, Notonectidae (Heteroptera), as well as Odonata

(Anisoptera, Zygoptera) and Ephemeroptera.

The absence of potential aquatic predators from most temporarary pools, hoof-prints and other small and transient water collections colonized by A.gambiae tends to suggest that there is little larval loss by predation (Service, 1973). Gillies and De Meillon (1968) stated that A.gambiae favours such sites as an adaptation to escape predation. However, adult flies have been observed settling on both small and large collections of water and preying on emergent adult mosquitoes and also on larvae (Service, 1970 b, 1973, Mogi et al., 1984). Larval predation appeared to be concentrated on the 4th instar. Among these predators were muscids belonging to a common species Lispe irvingi Curran and Dolichopodids (also Diptera) belonging to two species - Pelastoneurus congoensis Parent and Thinophilus species. Lycosid spiders have also been reported as predators of emergent mosquitoes by Bishop and Hart (1931) and Service (1970 b).

Estimates of the larval survivorship is an important component of the population dynamics of mosquitoes in any given locality (Reisen and Siddiqui 1979). Bates (1941) estimated larval survivorship by comparing the number of each instar collected divided by the instar duration for different habitats. More recently, several other workers, including Service (1971, 1973, 1976), Lakhani and Service (1974), Reisen and Siddiqui

(1979), Reisen et al. (1982), and Mogi et al. (1984, 1986), have used the method of age-specific life-tables developed by Deevy (1947) and Southwood (1978) for agricultural pests to estimate the survivorship of mosquito larvae.

1.3.2

Adults Mortality and Survivorship

The pioneering work in the use of physiological changes in the reproductive organs of adult female mosquitoes to estimate their longevity was done by Russian entomologists, chief among whom were Polovodova, Beklemishev and Detinova (Detinova, 1962; Gillies and De Meillon, 1968). All the blood-sucking Diptera show the phenomenon of gonotrophic concordance, that is, a ful blood-meal is necessary for the maturing of one egg batch. The period from the time a blood-meal is taken to the time of oviposition of mature eggs makes up a gonotrophic cycle and the number of cycles undergone by a female constitutes its physiological age (Detinova 1962). The Russian scientists worked mainly on Anopheles maculipennis Meigen but the principles have since been used on other mosquito species by other workers including Detinova and Gillies (1964) in Tanzania on A. gambiae and funestus, Gillies and Wilkes (1965) again on gambiae and funestus in Tanzania, Kay (1979) in Queensland, Australia, Samarawickrama (1962), Samarawickrama

et al., (1987), and Russel (1986) in northern Australia, on different species of culicine mosquitoes.

The simple method of determining daily survival rates based on the parous/nulliparous ratios has found much wider application in various parts of the world - Davidson and Drapper (1953), Davidson (1954), Gillies and Wilke (1963), Clement and Patterson (1981). A modified version of the parous formula has also been proposed for use in situations where recruitment of nulliparous females into the population is not constant (Birley and Rajagopalan, 1981). Birley and Boorman (1982) used this to estimate survival and biting rates of haematophagous insects in southern England while Mutero (1985), and Mutero and Birley (1987) used it to estimate the survival rates of malaria vectors in Kenya.

1.4 Vector Behaviour

1.4.1 Biting Activity

The biting cycles of the major malaria vectors in Africa, especially A. gambiae and A. funestus have been extensively studied and documented in parts of East and West Africa (Haddow, 1942, 1945, 1954; Van Someren et al., 1958; White, 1974; Krafsur, 1977; Mutero et al., 1994;

Muirhead-Thomson, 1948; Holstein, 1954; Hamney, 1960; Service, 1963; Snow et al., 1987). The general picture that has emerged from these and other studies is that there is usually a period of low activity between dusk (1900 hrs) to about 21 hours. From then on, there is increased activity, reaching a peak between midnight and 0400 hours. The biting remains fairly high until just before dawn when there is another peak. This increased activity at dawn is thought to be due to an influx of mosquitoes entering the house to seek shelter for the day (Haddow, 1942; Krafsur, 1977).

For both A. gambiae and A. funestus the bulk of the feeding takes place indoors. This is primarily connected with the late feeding habits of the sepcies. In southern Arabia where people sleep outside at certain times of the year, most biting takes place outdoor (Gillies and De Mellion 1968). However, Dunkeen and Omer (1986) stated that outdoor biting activity by A. arabiensis in northern Sudan occurred throughout the night with a peak between 2100 and 0500 hours. Feeding also rarely takes place during daytime, although Haddow et al. (1947) recorded small numbers of A. gambiae feeding during the day in Ugandan forests. There have also been records of daytime feeding by A. funestus (Gillies and De Meillon, 1968; Smith 1955, a).

1.4.2 Resting Habits

A. funestus is highly endophilic and spends a greater part of its adult life in houses (Gillies and De Meillon 1968). Very few A. funestus leave the house the same night after feeding. Several workers in East Africa established that only between 2 and 12% of fed females leave the house the same night (Muirhead-Thomson, 1951 a; Gillies, 1954 a; Draper and Smith, 1957, Smith and Draper, 1959 a; Haddow and Ssenkubuge, 1973). Service (1963) found 23% of fed females leaving the house after feeding in northern Nigeria. Many females which leave re-enter other houses the same night to rest (Haddow, 1942); Krafsur, 1977).

Early reports of the daytime resting behaviour of A. gambiae s.l. were conflicting. Some workers stated categorically that A. gambiae is essentially endophilic and spends most of each gonotrophic cycle resting inside houses. Muirhead-Thomson (1951 a) found that only 2% of fed females left houses after feeding. Gillies (1954 a, b) found 6 - 7% while Wilson (1960) found 5 - 12% leaving the houses soon after feeding. All these were in East Africa. On the other hand some workers in West Africa found large percentages of fed females leaving the houses soon after feeding. For example, Gelfand (1955) in Liberia and Muirhead-Thomson (1948) in Nigeria observed that as much as between 4 and 98% could leave the houses after feeding.

The main reason for this type of very wide differences in results is now known to be due to differences in behaviour between the various sibbling species of the A. gambiae comple . With the separation of the complex into six clearly defined (genetic) species it became possible to reconcile the conflicting results of earlier workers with regard to behaviour patterns. It is now generally accepted that A. gambiae s.s. (species A) which thrives in zones of forest and humid savanna, is predominantly endophilic and anthropophagic in behaviour (White, 1974; Highton et al., 1979; Mosha and Subra, 1982). Wherever man is readily available as a host, the human blood index (HBI) is very high and nearly all endophagic females remain indoors for at least the first day after feeding (Davidson and Draper, 1953; Gillies, 1954 a,b, 1956).

A. arabiensis (species B) on the other hand is genetically endowed to alter its behaviour much more easily in response to environmental situations (White, 1974). Its behaviour patterns are therefore more complex and more difficult to describe. Under natural conditions where a majority of hosts and domestic animals are indoors at night, the bulk of species B females feed indoors and remain there to rest for one or two days (Smith and Draper, 1959; White, 1974). When a high proportion of hosts (man or animals) are available outdoors at night, species B females feed outside

and then may enter the house to take shelter. However, if suitable outdoor resting sites are also available in addition to outdoor hosts, this species becomes predominantly exophagic and completely exophilic (White, 1974; Joshi et al. 1975; Highton et al.,1979; Dunkeen and Omer, 1986).

These differences in behaviour between species A and B of the A. gambiae complex also account for the differential results of house spraying with insectcides where the complex is the main vector. Species A does not have the genetic capacity to develop true behavioural resistance to insecticides (White, 1974). House spraying with residual insecticides is therefore likely to be very effective against endophilic species A populations. Faced with insecticidal spraying of houses, species B on the other hand readily selects for complete exophily, or at least postprandial exophily (Kuhlow, 1962; Smith, 1962 a,b,Pringle, 1967; White, 1974).

The saltwater species of the A. gambiae complex, namely A. melas and A. merus are generally more exophilic and exophagic than their fresh-water relatives (Iyengar, 1962; Mutero et al., 1984). Even in unsprayed houses, endophagic A. melas and merus tend to be exophilic for resting purposes, but this tendency increases after spraying (Snow et al.,1987).

1.4.3. Host Preferences

In reference to A. gambiae s.l., Gillies and De Meillon (1968) observed that in general, coastal and forest areas tend to be associated with the highest degree of anthropophily

while savanna populations tend to show higher levels of zoophily. It is now known that these two types of geographic conditions favour species A. and B. of the complex respectively. Davidson and Draper (1953) found more than 90% of catches from all situations in parts of East Africa to be positive for human blood. Gillies (1954 a, 1956) at Muheza, Tanzania got a human blood index (HBI) of 92%, Highton et al.(1979) found 92% of A. gambiae s.s. in the Kano Plains of Kenya to have fed on man while Arap Seroney et al. (1985) obtained 90.3% in the Kisumu area of Kenya. In a review of the subject Bruce-Chwatt and Gockel (1960) noted that the range in most parts of East and West Africa is between 41-86% positive for human blood in A. gambiae s.l. Exceptionally low indoor HBI values of 50% (White and Rosen, 1973) and 28% (Service, 1970 b) have been obtained where man is outnumbered by cattle inside houses at night.

The general concensus is that A. arabiensis feeds predominantly on hosts other than man. Where species A and B coexist, therefore B usually has a lower HBI than A. For example, White et al. (1972) found an HBI of 91.2% and 60.9% for species A and B respectively in indoor biotope and 2% and 7% for the two species respectively in outdoor biotope while Highton et al. (1979) found 92% and 59% for the two species respectively in indoor catches. Thus, as White (1974) pointed out zoophily in species B is a matter of degree. Wherever man is present, he is bitten in considerable numbers and HBI of 100% have been found in small samples taken from

human habitations.

In keeping with their predominantly exophilic tendency, the saltwater species, A. melas and merus also tend to prefer non-human hosts but bite man consistently in the absence of these other hosts. Iyengar (1962) found 59% of house catches positive for human blood and less than 2% of outdoor catches positive for human blood in A. merus in Pemba island. But Mutero et al. (1984) found as high as 59.8% of their outdoor catches at Jimbo, Kenya Coast positive for human blood.

The degree of anthropophily recorded for A. funestus by various workers is also very variable. Haddow (1942) had a value of 98% in Kisumu, Kenya; Bruce-Chwatt and Gockel (1960) recorded 98.6% in Liberia, 94% in Ghana and 89% in Nigeria. White et al. (1972) recorded 97.5% for indoor biotope and 24% for outdoor biotope. On the other hand, Bruce-Chwatt and Gockel (1960) in mixed habitations and outdoor shelters in Upper Voltar found only 24-26% of their catches positive for human blood and Zulueta et al. (1963) found that 43% of house catches in Uganda contained human blood.

1.5. Irrigation and Mosquito Breeding

The building of irrigation schemes, dams or man-made lakes disturbs the ecological balance of the surrounding region and may have adverse effects on human health by promoting the breeding of disease vectors (Stanley and Alpers, 1975; Maddy

1973; W.H.O., 1967, 1982; Youdeowei and Service, 1983). Irrigation influences mosquito breeding by providing new or increased water body for breeding and introducing new or more vertebrate hosts. They also lead to villages and settlements and the insanitary habits of the inhabitants may create new habitats for mosquito breeding (Paterson, 1964 a, b).

Rice as the major crop related to water storage and irrigation, contributes to mosquito production on a global scale (Gillies and De Meillon, 1968; Surtees, 1975; Youdeowei and Service, 1983). Macdonald et al.(1967) observed that rice cultivation was responsible for increased populations of Culex tritaeniorhynchus Giles throughout tropical Asia, India and Japan. Similar conclusions were reached by Nogi et al. (1984, 1986) in the Philippines and northern Thailand with respect to Anopheles peditaeniatus Leicester and A. sinensis Weidemann. According to Surtees (1975), flooding of rice fields in Venezuela in May/June is usually followed by sharp increases in the populations of A. albimanus Weidemann and A. pseudopunctipennis Theobald.

The epidemiology of arbovirus diseases associated with rice cultivation has been studied extensively in Sarawak and other parts of south-east Asia (Smith, 1970; Heathcote (1970; Hill, 1970; Simpson et al., 1970; Surtees, 1970 b) Heathcote (1970) stated that the Japanese encephalitis virus in Sarawak was transmitted by Culex gelidus Theobald which fed

exclusively on pigs and C. tritaeniorhynchus which fed on both man and pig. C. tritaeniorhynchus bred profusely in rice fields and its breeding activity was closely related to agricultural practices throughout the year. There were two peaks in its population, the major peak occurred in September/October just before planting and was thought to be due to increased breeding as a result of preparation of rice fields for cultivation. The second peak occurred after harvest in April/May (Heathcote, 1970; Hill, 1970). Similar results were also obtained by Surtees (1970 c) who studied mosquito breeding in the Kuching area of Sarawak with special reference to dangue fever.

Reuben (1971) in his studies of the breeding sites of mosquitoes of north Arcot district, Madras, India found that Culex vishnui Theobald, C pseudovishnui and C tritaeniorhynchus were all breeding in rice fields but were abundant at different times of the year. C vishnui were most abundant in fallow rice fields while C pseudvishnui and C tritaeniorhynchus were most common in planted rice fields.

The transmission of arbovirus by mosquitoes breeding in irrigation schemes in Kenya has also been studied extensively. Bowen et al. (1973) found high prevalence rates of 'O'nyong-nyong' (59%) and 'Chikungunya' (61%) viruses among people living in Ahero and Kano Plain irrigation areas. These viruses were transmitted by A. gambiae and A funestus which breed in high numbers in irrigated fields. West Nile virus was also present in low endemic proportions, maintained by birds and Culex antennatus Beck which bred in large numbers in the rice fields at certain stages of the rice cultivation cycle (Surtees 1970 a, Bowen et al 1973).

Mosquito breeding in relation to an irrigation project in Kenya has been studied extensively in the Ahero rice irrigation scheme (Surtees, 1970 a; Simpson, 1975; Chandler and Highton, 1975; Chandler, 1976; Highton et al., 1979). Surtees (1970 a) studied the arbovirus disease epidemiology in relation to large scale irrigation in the Kano plains. He compared species composition and relative abundance of man-biting mosquitoes on the irrigation scheme and on an undisturbed area and found that in the villages adjacent to

the rice fields, A. gambiae Giles made up 65% of the catch; Mansonia uniformis Theobald 28% and Culex P fatigans Weid 5% while in the villages in the unmodified area Mansonia uniforis constituted 86% of the catch; A. gambiae less than 1% and only 3 Culex p fatigans (C.quinquefasiatus) were taken. Larvae of A. gambiae were most abundant in nursery paddy while among older, denser plants C. antennatus was the dominating species.

Chandler and Highton (1975) studied the succession of mosquitoes in rice fields in Kisumu area of Kenya and recognised two groups:- (a) Those that bred throughout the rice cycle, including Mansonia uniformis and M africanus (b) Those that were affected by the water depth and height of the rice crop, including A. gambiae, A. pharoensis, A. ziemanni Grunberg and Culex poicilipes Theobald. The slurry of shallow muddy pools which follow transplant stimulated intense breeding of A.gambiae and A. pharoensis. Reflooding and rice growth favoured A.ziemanni and C.poicilipes

Chandler (1976) also studied the mosquito fauna of irrigated and non-irrigaed areas of the Kano plain. He collected large numbers of A. gambiae s.l., A.ziemani and A. pharoensis on the Aharo pilot rice scheme while on the non-irrigated Kano plain catches were made up predominantly of M. uniformis

an M. africanus Theobald. Similar results were obtained by Simpson (1975) who also noted that the peak populations began to occur a month earlier in the irrigation scheme than elsewhere and were maintained over a longer period and that the breeding activity of each species was related to rice cultivation.

Apart from rice, nearly every other crop such as cotton, banana, etc requiring irrigation supports mosquito populations of medical importance (W.H.O., 1982; Youdeowei and Service, 1983)

Dams provide important breeding grounds for malaria vectors such as A.gambiae complex and A.funestus in Africa, A.hyracanus Pallas in Asia and A darlingi Root in South America (Macdonald, 1955; Youdeowei and Service, 1983). There are many large dams and man-made lakes in Africa, including the lake Kariba on the border between Zambia and Zimbabwe, lake Nasser in Egypt, Volta lake in Ghana and Kainji lake in Nigeria. But with the exception of the Volta and Kainji the medical implications of the projects were not thoroughly investigated befor constuction work began (Balfour Beatty and

Nedeco, 1963; Waddy, 1975; Imevbore, 1975). Malaria which was endemic in all the areas (except Egypt) before the dams were built has remained a major problem and in almost all the cases has escalated as a result of the construction of dams (Youdeowei and Service, 1983.

Paterson (1964 a, b) had earlier strongly recommended that mosquito studies should be started at an early stage of any irrigation or dam project. It is important from the very beginning to predict how the particular dam under construction is likely to influence mosquito production and what dangers to the health and comfort of man are likely to result from these influnces. It follows from this that each irrigation or dam must be treated as a unique case since what happens in any particular case depends on:

(i) The nature of the dam and the use to which it is put, and

(ii) The mosquito fauna of the broad geographical region in which the dam is situated (Farrid 1975, Paterson 1975).

CHAPTER 2

GENERAL MATERIALS AND METHODS

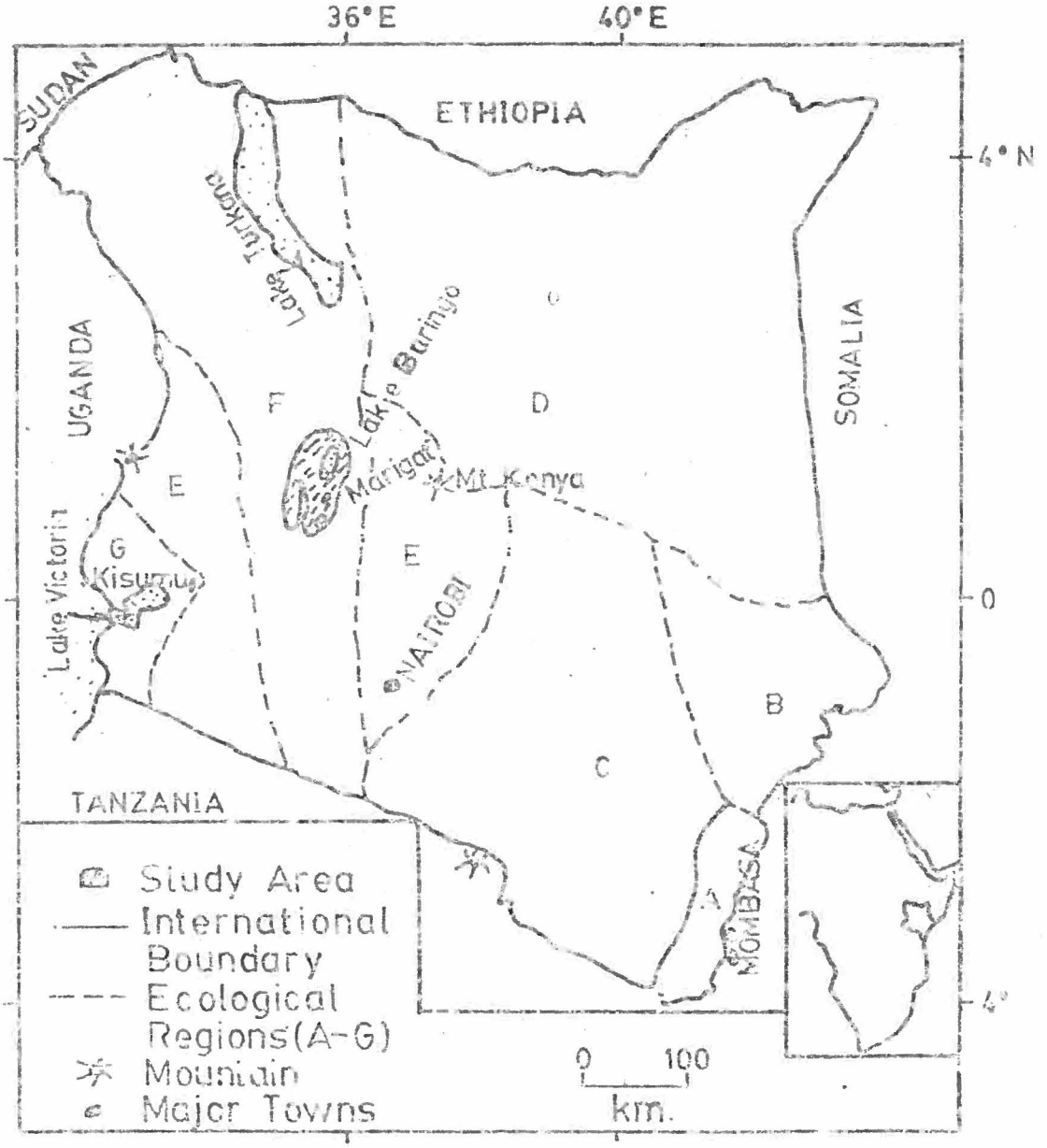
2.1 The Study Area.

2.1.1 Location

Marigat division is in Baringo district, Rift Valley Province of Kenya (see Figs. 1,2). It is very close to the Equator, lying between latitude 0.45°-1° 10' north and longitude 36° - 37° 30' east, at an altitude of about 1005 meters above sea level. The part of the division included in this study is bounded by Lake Baringo to the north and Lake Bogoria to the south. The main Nakuru-Marigat highway marks the west western boundary. It is a flat, low-lying area ringed on all sides by a range of hills. The two lakes are approximately 40 km apart and Marigat town is about half way between them. Marigat is about 250 km north-west of Nairobi and about 100 km north of Nakuru, 20 km south of lake Baringo. Kabarnet, the district headquarter is 40 km west of Mariget and the two are linked by a tarmac road.

2.1.2 Climatic Conditions

The area is semi-arid with an annual average rainfall of about 600 mm. The long rainy season is between March and June, while the short rains are between October and December, but in most cases are either for scanty or entirely absent. Thus there is a long dry period between August and March, characterised by high temperatures and dust, especially between January and March. Temperatures vary, 16-$38^{\circ}C$, and evaporation rates average 6 mm per day.



REGIONS. A- Coast, B- R. Tana Basin, C- Savanna Plateau, D- Dry Savanna, E- Highland, F- Rift Valley, G- Lake Victoria Basin

Figure 1: Map of Kenya showing the Malaria Ecology study Area and the different Ecological Regions of the country.

The soil is light silt to clay loam, considerably alkaline, with an average pH of 7.5. It is low in organic matter, rich in calcium phosphate (Anon., 1987 a, b). The area is sparsely wooded, with the thorn Acacia as the most common tree. There is, however, an ambitious tree planting and afforestation programme being under-taken by the Department of Forestry and supported by the United Nations Environmental Programme (UNEP). During and immediately after the rains (April-July), the ground is covered by a carpet of fast maturing grasses, giving it a temporary green outlook.

2.1.3 The Permanent Bodies of Water

Marigat division has a number of permanent bodies of water, both natural and man-made (see Fig 2). Many of these waters support mosquito breeding all round the year. Two of these were selected to form the main points of in-depth studies for this project. These are the Perkerra irrigation scheme as an example of a man-made breeding site and the Loboi swamp as example of a natural breeding site. The larval ecology studies were conducted at these sites. The adult sampling sites were all located close to them, except Endau village. A brief description of the main features of these two bodies of water is given below.

The Perkerra Irrigation Scheme

The Perkerra river is the largest all-season river in the study area and it supplies the water used for the irrigation scheme. The scheme is located 5 - 8 km east of Marigat. It covers an area of 5,850 acres (about 2,370 hectares), out of which 1,704 acres (690 hectares) are put under cultivation

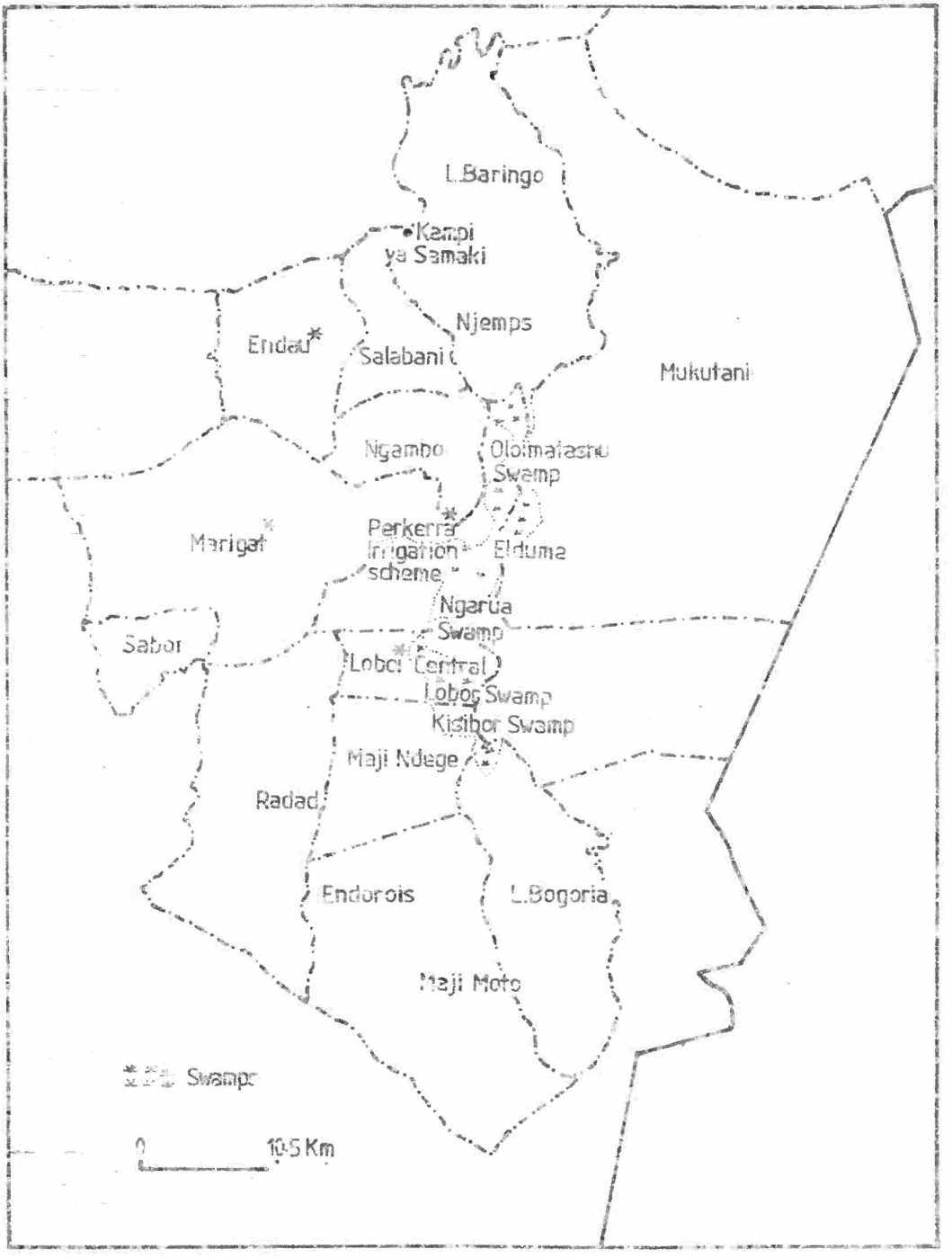


Figure 2. Map of Marigat division, Baringo district, showing the main sampling sites and permanent bodies of water.

*Main sampling sites.

annually. A method of inclined plane irrigation is used. The water flow depends completely on gravitational forces, without any mechanical pumping of water. More than 80% of the scheme (1,365 acres) is covered in this way, while the remaining 339 acres are under the level basin irrigation. Water levels in the main canal and the secondary canals are maintained by means of "protection river wares". These are devices by which the water flow is restricted at intervals along the canals in order to allow the level to rise to a desired height, thereby increasing its speed of flow when the restriction is removed.

There is one main canal leading from the dam on the Perrera river which divides the whole scheme into two halves (Fig 3). Branch canals lead off from this and pass in between the plots. From the branch canals smaller feeder canals carry water into the cultivated farms. The cultivated plots are made into 'basins' each measuring about 4 x 3 meters. These are separated from one another by 'furrows' about 10 cm deep. Water flow is permanent only in the main canal. In the branch and feeder canals water is allowed to flow only once a week. That is, the crops are flooded once a week to a depth of 10 cm after which the water is cut off. This is unique and very different from most other irrigation schemes where the crops are flooded for prolonged periods of 3-9 months at a time. Thus, even though crops are grown all year round, there are no stagnant pools within the plots for any considerable period of time. This is particularly so during the prolonged dry season, September - March. The canals are weeded at regular intervals, the main canal by the irrigation board and the branch and

Figure 3: A part of the Parkerra irrigation scheme, showing the main channel.

a range of hills and is created by small streams and springs sprouting from the hills. Run off water from the hills also empty into the swamp. The water is alkaline (mean pH = 8.3) and contains a lot of decaying organic matter from the covering vegetation. There are many small villages around the swamp. The two largest villages were selected for this study. Kapkuikui is situated near the Marigat end of the swamp. A dug-out canal draining the swamp provides the villagers water for domestic use and small scale irrigation. The other village is Tingttiyon. It is located 5 km from kapkuikui at the other end of the swamp. The first group of houses is 2 km from the swamp. There is an all season river, River Loruwai, which passes through this village, forming a temporary swamp in some part of it, thereby creating a micro-environment which affects mosquito breeding in the area. This river has its source in the Mogotio highlands, about 60 km south of Marigat and empties into Lake Bogoria, some 10 km after Tingttiyon.

2.1.4 The Inhabitants

The area is inhabited mainly by the Tugens, with smaller numbers of Njemps and Turkanas. The people are organized in small family units. Several units constitute a settlement or a village. Each family unit has a cluster of 3-6 houses, close to one another and enclosed by a fence of thorny acacia branches. There is usually a separate house for the head of the family, one for the wife and children and one each for any adolescent male child. All of these may be shared by animals unless separate houses have been built for the animals. The staple foods are maize meal, milk and meat. People normally

Figure 4: A section of the Loboi Swamp, showing the thick Papyrus cover.

retire for the night around 8.00 p.m. except on special celebrations such as wedding or when children gather to sing and play in the moonlight during the dry season.

All the settlements and villages are small. RI and RJ on the irrigation scheme have 40 residential houses each and 150 inhabitants per settlement. Endau village is also about the same size. Kakpuikui and Tingttiyon villages near the Loboi swamp have 60-80 residential houses, with 200 and 300 inhabitants respectively per village. Water for domestic use is obtained from the irrigation canals in the case of the settlements near it and from the Loboi swamp in the case of the villages near it. Residents of Endau get their water from seasonal rivers and temporary pools during the rainy season and from Marigat town (5 km away) during the dry season. An irrigation scheme which will carry water from the Chemeron artificial lake to Endau was still under construction.

2.1.5 Occupation

The people are traditionally semi-nomadic herdsmen and animal husbandry is the most important occupation. The farm animals include cattle, sheep, goats and donkeys. Most people also keep a few chicken, dogs (serve as guards) and pet cats. Men and animals live in very close promimity, sharing the same houses or sleeping in separate houses close to one another. People with large numbers of animals often keep them in open enclosures within the compound. The animals are taken out for grazing in the morning, 8.00 a.m - 9.00 a.m. and brought back in the evening (6.00 p.m.). Crop farming is on a small subsistence scale by a s.minority of the population, outside the

irrigation scheme area and the government is intensifying efforts to popularize irrigation farming. The main subsistence crops are maize, beans, sorghum and bananas. On the Perkerra irrigation scheme the cash crops are onions, pepper and water melon. The resident farmers also plant maize, beans, tomatoes and vegetables for local consumption.

2.1.6 Housing

Nearly all the houses in the area are loosely constructed and semi-temporary in nature (Fig 5). The roof is thatched with grass or with dry papyrus leaves. The walls are made of acacia sticks, plastered with a mixture of mud and cow dung. Each house consists of a single room measuring 2-2.5 square metres, and is usually circular in shape. Some of the houses are elevated on poles to a height of 1 to 1.5 metres. This type has the sleeping apartment 'upstairs' while the ground floor serves as animal house and kitchen. In Marigat township, most of the houses are of the semi-permanent type, with walls made of wood or iron sheets and roofs of corrugated iron sheets. This type is also common at the shopping centres in the settlements.

2.2. Pre-Study Survey and Preliminary Sampling

A pre-study survey of Marigat division was conducted early in October, 1985. It involved traversing the area several time, using a car, a bicycle or on foot (whichever was more suitable) in order to establish the following:

(i) Location and extent of the permanent sources of water.

(ii) Distribution of human settlements and their domestic sources of water.

Figure 5: Thatch-roofed house common in the study area.

(iii) Accessibility or otherwise of the permanent bodies of water by road at different times of the year.

(iv) Any other topographical features of the area which may be relevant to mosquito breeding and survival, such as presence of caves, animal burrows, thickets, deep rock crevices, termite hills etc.

The pre-study survey also involved extensive tour of the Perkerra irrigation scheme in order to ascertain its basic lay-out and essential features. Discussions were held with the staff of the irrigation board for background information on the mode of operation of the scheme. Discussions were also held with the staff of the Rural Health Centre and the Division of Vector Born Diseases (D.V.B.D) in Marigat for information on the incidence and level of malaria. Two public meetings (baraza) were organized with the assistance of the locational chiefs at Loboi and Endau during which the inhabitants were informed of the proposed project. They were given the outlines of the work, the likely inconveniences it would cause to them and the possible benefits that would acrue from it in the future. Finally, the areas of co-operation and assistance needed of them especially with regard to the early morning pyrethrum spray inside houses, were discussed and mutually agreed upon.

From observations made during the pre-study survey and from analysis of available data, a tentative list of candidate localities for data collection was compiled. Preliminary sampling was then undertaken in these localities between mid-October 1985 and end of November 1985. Four methods were

used for adult mosquito sampling, namely:

(i) Hand collection using sucking tubes to collect mosquitoes from animal sheds, vegetations, borrow pits, and other outdoor resting sites. Each site was sampled for 15 minutes on each of two visits during the period.

(ii) Suction trap collection which consisted of the use of a modified Monkswood trap to collect mosquitoes from animal burrows and termite hills between 6.00 p.m. and 6.00 a.m. One such collection was made every week from each type of resting site.

(iii) Early morning collection of indoor-resting mosquitoes by the pyrethrum spray method.

(iv) Use of exit traps to sample mosquitoes that were leaving the houses after entry between 8.00 p.m. and 6.00 a.m.

The efficiency of the outdoor sampling methods could not be compared statistically because the units sampled, that is, vegetation, animal burrow etc, were different in size and it was very difficult to standardize the catches for purposes of comparision. The pyrethrum spray method was found to be significantly more efficient than the exit trap in sampling house-haunting mosquitoes. It should be noted, however, that the two methods sampled different subunits of the population. The spray method sampled daytime house-resting mosquitoes consisting mainly of freshly fed females whereas the exit trap sampled unfed females leaving the house in search of other hosts and exophilic members of the populations seeking outdoor resting sites. The exit trap was discontinued when routine

sampling was started in January, 1986 not only because of its low productivity but also because it was unsuitable for the type of houses in the study area. Most of these houses were without windows, making it extremely difficult to fix the exit traps.

A larval survey involving the examination of all the existing or potential breeding sites was also carried out. Different parts of the major permanent bodies of water in the area, namely the irrigation scheme, the Loboi Swamp, Lakes Baringo, Bogoria and Chemeron, as well as temporary pools and puddles in existence at that time were sampled once a week by the use of dips. Ten dips were taken from each type of habitat per sampling occasion.

The following four localities were eventually selected for routine sampling, based on their nearness to the two main breeding habitats, Loboi swamp and Perkerra irrigation scheme, and their accessibility by road throughout the year:

(a) Kapkuikui and Tingttiyon villages, near the Loboi Swamp. These were the largest in size and most populate of the several small, semi-temporary settlements near the swamp. The two villages were approximately 5 km apart.

(b) Locations R7 and R5 on the Perkerra irrigation scheme.

These two settlements were in the middle of the scheme and of about equal sizes. They were approximately 3 km apart.

(c) Endau village about 5 km north of Marigat town. There was no permanent source of water here and it was chosen as an example of a locality where mosquito breeding depended entirely on temporary habitats created by local rainfall.

Marigat township was chosen as a fourth sampling location but was abandoned after only two months (in February 1986). There were two reasons for this abandonment - firstly the inhabitants of Marigat township showed extreme reluctance and very often outright refusal to the use of their houses for spray collection. The explanation for this was the inconvenience of moving a large assortment of household effects anytime the spraying was done. Secondly the houses in Marigat were very different in materials, construction and size from those in the other three locations. This would make any comparisons of results extremely difficult.

2.3 General Sampling Methods

2.3.1 Pyrethrum Spray Collection

This method was used to sample indoor resting adult mosquitoes for various purposes between October, 1985, and September, 1987. The procedure used in this study was as described by the W.H.O. (1975 a). Since there were 40 - 80 houses in each sampling location, five houses were selected in each of the sampling locations, so that on the average one house in ten was sampled. These were sprayed once every fortnight, using a solution of 2.4% pyrethrum, diluted with water in the ratio of 1:50. The spraying was done between 6.00 a.m. and 9 a.m. The houses in the sampling locations chosen were very ideal for this method of collection. They were single-roomed, without windows and with very few household effects. In each location the same five houses were used throughout the period of the study. Each house in each location was given a number (1 to 5) and mosquitoes from each house were put in a plastic tube lined with filter paper with a corresponding number for that house. All identifications, dissection etc were undertaken in the laboratory.

The mosquitoes collected by the above method were used (1) for the study of the species composition, relative abundance and seasonal fluctuations of the indoor resting populations and (2) to provide materials for dissections etc for the study of age composition, sporozoite rates, host perferences etc.

2.3.2 Searching Method

This method was used to sample adult mosquitoes from different outdoor resting sites. Vegetations around breeding sites and residential houses, animal enclosures, borrow pits and store houses were sampled twice a month in each of the sampling locations. Each type of resting site was searched for 10 minutes on each occasion, using sucking tubes to collect the mosquites.

The mosquitoes collected by this method were used to study the resting behaviour (endophily/exophily), the species diversity and the host perferences of the mosquitoes.

2.3.3 Suction Trap Collection

A modified version of the miniature CDC trap designed by Birley and Mutero (pers. comm) was used to collect mosquitoes resting inside animal burrows and termite hills. The trap consists of a 12 volt motor to which a small fan has been attached. The motor and fan are mounted inside a plastic water pipe, 10 cm in diameter and 20 cm long, so that the fan is 5 cm from the lower end of the pipe. The motor is powered by four 1.5 volt-torch batteries or a 12 volt-rechargeable battery. A collection bag of nylon netting material is attached to the opposite end of the pipe (Fig. 6). When the trap is switched on, the fan rotates and any insect that comes close enough is drawn in by an up draft suction mechanism into the collection bag.

Figure 6: The miniature CDC suction trap used for sampling animal burrows.

There was a fortnightly reshuffling of the team mates. This was intended to minimize any bias introduced into the results by differences in individual efficiency and attractiveness to mosquitoes (Haddow, 1942). Collecting simultaneously from inside and outside ensured that partially or completely exophagic as well as the endophagic mosquitoes were collected.

The landing/biting catch method was used in this study to estimate the biting cycles of the major anopheline species. Some of the mosquitoes were dissected for the purpose of calculating the survival rates, using the parous/nulliparous ratio.

2.2.3 Larval Collection Method: Dipping

Dipping was used for sampling breeding sites for larvae. The dipper consisted of an aluminium bowl, 15 cm in diameter and 5 cm deep, with a handle about one meter long. Two locations on the irrigation scheme (R5 and R7) and parts of Loboi swamp were sampled fortnightly between January and December 1986 for the population dynamics study. Ten dips were made at pre-determined points in each area on every sampling occasion. An interval of 2 - 3 minutes was usually allowed between dips so as to permit the larvae and pupae to return to the surface after being disturbed. Where the water surface was covered with vegetation, as in parts of the Loboi swamp, the vegetation was agitated and then cleared off before depping, in order to dislodge any larvae clinging

to it. The larvae were removed by siphoning into bottles. They were transported live to the laboratory for identification and counting.

This method was used to monitor the active breeding sites of the various species throughout the period of the study. It was also used to study the population dynamics of the aquatic stages at different times of the year at both Loboi and Perkerra.

2.4 Identification of Mosquitoes

All identifications were made in the laboratory. Both adults and larvae were identified. On every sampling occasion some of the larvae collected were reared to adults in the laboratory. The adults which emerged from those larvae were identified independently to cross-check the previous identification. In cases of doubt or where a specimen could not be identified by us at Marigat, the specimen was sent to the National Museum (Natural Sciences Division), Nairobi, for identification.

The keys used in the identification of the mosquitoes were those developed by Edwards (1941), Mattingly (1944), Hopkins (1952), Gillies and De Meillon (1968), and Highton (1983).

2.5 Statistical Methods

The following statistical methods were used in the analyses of the data collected.

2.5.1 Correlation

Some of the data collected were of the bivariate-normal type in which one variable (x) appeared, from a scatter diagram, to have a rectilinear relationship to another variable (y). This type of data was collected in the course of investigating the following:-

(a) the relationship between the relative abundance of *Anopheles* mosquitoes and changes in climatic factors such as rainfall, relative humidity, temperature, and windspeed.

(b) the relationship between the numbers of mosquito pre-imagines and their developmental time.

(c) the relationship between sporozoite infection rates in mosquitoes and the prevalence of malaria in the local population.

In each of these, the correlation coefficient (r) was calculated as a measure of the degree to which x and y vary together, using the method of Parker (1979). The calculated value of r was then compared to its corresponding value on a table of critical values of r in order to test the significance of the observed rectilinear relationship. The values of r^2 and $1 - r^2$ were also calculated to estimate what proportions of the variance of y were associated and not associated with x in a linear regression (Snedecor and Cochran, 1980).

2.5.2. REGRESSION AND ANALYSIS OF VARIANCE (ANOVA)

The establishment of a significant rectilinear relationship between two variables, x and y, by calculating the correlation coefficient r, does not prove a causal relationship between the two (Snedecor and Cochran, 1980; Bailey, 1981). A regression analysis is needed before any such conclusion can be made on whether changes in the values of y are caused by changes in the values of x. Therefore in the bivariate-normal data mentioned above a regression analysis was done if the value of r was significant at 5% or lower. The regression equation, $y = a+bx$, was used to estimate "b", the coefficient of regression from the sample data, and "a" the intercept (Parker, 1979).

After the regression line was fitted, the significance of the regression was tested by an anaylsis of variance, especially in those cases where the points were well-spread about the regression line. The F-ratio calculated was then compared with corresponding values on a table of F-ratios. It was therefore possible to conclude whether or not there was a linear relationship between x and y in the parent population.

2.5.3. Life-Table Analysis

The stage-specific survivorship of immature Anopheles mosquitoes in two habitats in the study area was calculated using the procedure outlined by Service (1973). The number entering each stage (S_1) was estimated from the survivorship curve. The survivorship from 1st instar to adult was then calculated as S_1 (adult)/S_1 (1st instar) while the "Killing Power" K (Varley et al 1974) of each stage was calculated as $\log_{10}S_1 - \log_{10}S_{i+1}$.

Life-tables were also calculated from the survivorship curves using the method of Southwood (1978). The tables contained the following columns:-

x = age in days

Nx = No surviving to age x

lx = No per 1000 surviving to age x

dx = mortality between ages x and x+1

px = probability of surviving from age x to x+1

qx = probability of dying between age and x+1

ex = expectation of life remaining for individuals of age x.

2.5.4. Chi-square (χ^2) Test

In the study of rates of infection with malaria parasites among school children the chi-square test (2x2 table) was used to test the significance of the differences in infection rates between different schools at different times of the year.

2.5.5 Formulae for Survival Rates of Adult Mosquitoes

The mean parous formula (Macdonald 1952) as modified by Davidson (1954) was used to estimate the daily survival rates of adult mosquitoes. According to this formula, the average survival rate per oviposition cycle, P, is calculated as follows:

$$P = \frac{\text{Total parous}}{\text{Total caught}} \qquad (1)$$

The daily survival rate (Pi) is obtained from the following equation: $P_I = n\,p$ (2)

where n is the duration of the oviposition period in days.

2.5.6 Transformations

The following transformations were made on some of the data before analysis:

(a) Log x+1 transformation was used for the number of mosquitoes caught in monthly samples, before they could be plotted against rainfall, temperature, etc. This transformation was necessary because the values of the catches varied widely and contained some zero catches (Parker, 1979).

(b) Log x transformation was used for the median age numbers of mosquitoes before plotting them against developmental time because of wide variations of their values.

CHAPTER 3

SPECIES DIVERSITY AND DISTRIBUTION

3.1 Introduction

In studying the ecology of malaria vectors in any locality, it is necessary to identify and document all the other mosquito species which share the same breeding sites and hosts with the target species. This is because since all the mosquitoes breeding in one habitat compete for the available resources such as food, space, shelter etc., knowledge of the distribution and relative abundance of the non-vectors may be essential in understanding the population dynamics of the vectors. Such a knowledge can be exploited when devising control measures, for example in situations where there is competitive displacement of one species by another (Subra and Dransfield, 1984)

Mosquitoes in the parts of Baringo district covered in this study were found to breed mainly in three types of habitats:

(i) The Lobei swamp

(ii) The Perkerra irrigation scheme

(iii) Temporary pools such as hoof-prints, borrow pits, car and tractor tracks etc.

The first two were large permanent bodies of water which supported mosquito breeding round the year while the third were transient and appeared only during or soon after the rains.

Rainfall, by creating new breeding sites such as the temporary pools and by replenishing the permanent ones such as the swamps, determines the seasonal distribution and abundance of mosquitoes. Other climatic factors like temperature, relative humidity, and windspeed affect the survival and activity patterns of adult mosquitoes (Muirhead-Thomson, 1982; Bruce-Chwatt, 1985). The population dynamics of the major malaria vectors in the study area, namely, Anopheles gambiae and A. funestus were studied in relation to the following climatic factors: rainfall, temperature, relative humidity and windspeed.

3.2 Materials and Methods

The mosquitoes used for the study of species diversity, distribution and relative abundance were collected using four methods:

(i) Pyrethrum spray collection

(ii) Use of sucking tubes

(iii) Suction trap collection

(iv) Human bait method.

The details of these methods of collection were given in Chapter 2. section 2,3 and 2,4.

3.3. Results

3.3.1 Species Diversity

A total of 17 species of mosquitoes were collected and identified over the 2-year period, October 1985 - October 1987. Seven of these were of the genus Anopheles and ten

belonged to various genera of the tribe Culicini. Seasonal changes in species diversity (places and periods of collection) are summarized in Table I

Table I: Summary of Places and Times of collection of various Mosquito species.

SPECIES	LOCATION	PERIOD	SITE
A.gambiae	Loboi	All year round	Indoors*, T.H, A.B
	Perkerra	" "	" "
"			
	Endau	May - December	" "
"			
A.funestus	Loboi	All year round	Indoors*, T.H, A.B
	Perkerra	Feb.- Mar.,	" " "
		Aug.- Oct.	" " "
A.pharoensis	Loboi	May - December	Indoors, Vegetation near animal enclosures*
A.coustani	Loboi	May - August	Vegetation near breeding sites
A.ziemani			
A.salbaii	Loboi	January - April	Indoors
A.Logipalpis	Loboi		

Table 1. Summary of Places and Times of collection of the various Mosquito species (CONTINUED).

SPECIES	LOCATION	PERIOD	SITE
A.rufipes	Loboi	Jan.-March	Vegetation near breeding sites
Mansonia africanus	Loboi	Oct.-Dec.,	Indoors, Vegetation around human houses
	Perkerra	Jan.-Apr,	
Aedes aegypti	Marigat town	April - October	In and near human houses
Ae.furcifer (Dicercmyia)	Loboi	April - July	Vegetation near animal enclosures
Ficalbia Lacustris	Loboi	Jan - Apr.	Indoors*
Ficalbia hispida	"	"	"

Cx zombiensis	Marigat town	All year round	Indoors*, A.B.T.H. Vegetation.
Cx. quinque-fasciatus	Loboi	" " "	" "
	Perkerra	Feb.-December	" " "
	Endau		" " "
Cx.peiclipes	Loboi	January - April	Indoors
Cx.vansome-rini			

KEY:

* = Most important collection site.

A.B. = Animal burrow

T.H. = Termite hill

3.3.2 Seasonal Abundance

The results of the pyrethrum spray catches from the four sampling locations for the period January to December 1986 are summarized in Table 2. The details of each individual species' collection from each location, including the sex ratios are given in Appendix 1.

From Table 2 it can be seen that during the hot dry season (January - March) A.gambiae was the most abundant species at Kapkuikui (Loboi) and Perkerra, followed by the culicines. But at Tingttiyon (Loboi) and Endau village the culicines weremost abundant at this time followed by A.gambiae. At Kapkuikui, A.gambiae numbers increased steeply in April following the onset of the rains in March, reaching a peak in May. There was an equally steep drop in June and thereafter the numbers remained moderately high and steady till August. From September there began a steady decline in numbers up to December (Fig. 7). At Tingttiyon there was a slower but steadier increase in A.gambiae numbers from March, reaching a peak in June and then dropping gradually to a low level in September. Between October and December there was another increase in numbers with a peak in November equalling that of June (Fig. 8).

The seasonal abundance of A.funestus showed three clearly defined population peaks during the year in the Loboi swamp area. The numbers increased steadily from January until March (at Tingttiyon) and April (at Kapkuikui) respectively. Thereafter there was a decrease in numbers during the heavy rains.

Table 2: Summary of monthly collections of mosquitoes indoors from 4 sampling sites in 1986. (Collections from 5 houses were pooled.

	LOBOI						PERKERRA			ENDAU		
	Kapkuikui				Tingttiyon		Rl			Endau Village		
MONTH	Gamb-iae	Fune-stus	Pharo.	Culi-cine	Gamb-iae	Fune-stus	Culi-cine	Gamb-iae	Fune-stus	Culi-cine	Gamb-iae	Fune-stus	Culi-cine
JAN.	40	4	0	16	30	11	72	4	0	0	-	-	-
FEB.	29	14	0	52	78	18	183	5	3	2	-	-	-
MAR.	87	42	0	49	128	74	293	9	3	7	0	0	6
APR.	111	83	0	50	144	54	257	13	0	23	0	0	38
MAY	546	40	18	52	173	41	23	14	0	7	27	0	0
JUNE	136	43	24	13	192	43	16	38	0	3	34	0	0
JULY	157	33	11	1	149	35	1	96	0	0	115	0	1
AUG.	123	184	8	30	129	97	7	203	5	0	29	0	0
SEPT.	82	104	2	26	58	23	6	255	9	0	58	1	1
OCT.	63	230	0	57	176	291	51	137	8	6	2	0	2
NOV.	35	561	0	174	196	70	24	37	0	4	4	0	0
DEC.	57	137	0	80	123	246	21	32	0	12	1	0	0
TOTAL	1466	1475	63	600	1576	1003	954	845	28	64	270	1	48
%	40.7	40.9	1.8	16.6	44.6	28.4	27.0	90.2	3.0	6.8	84.6	0.3	15.1

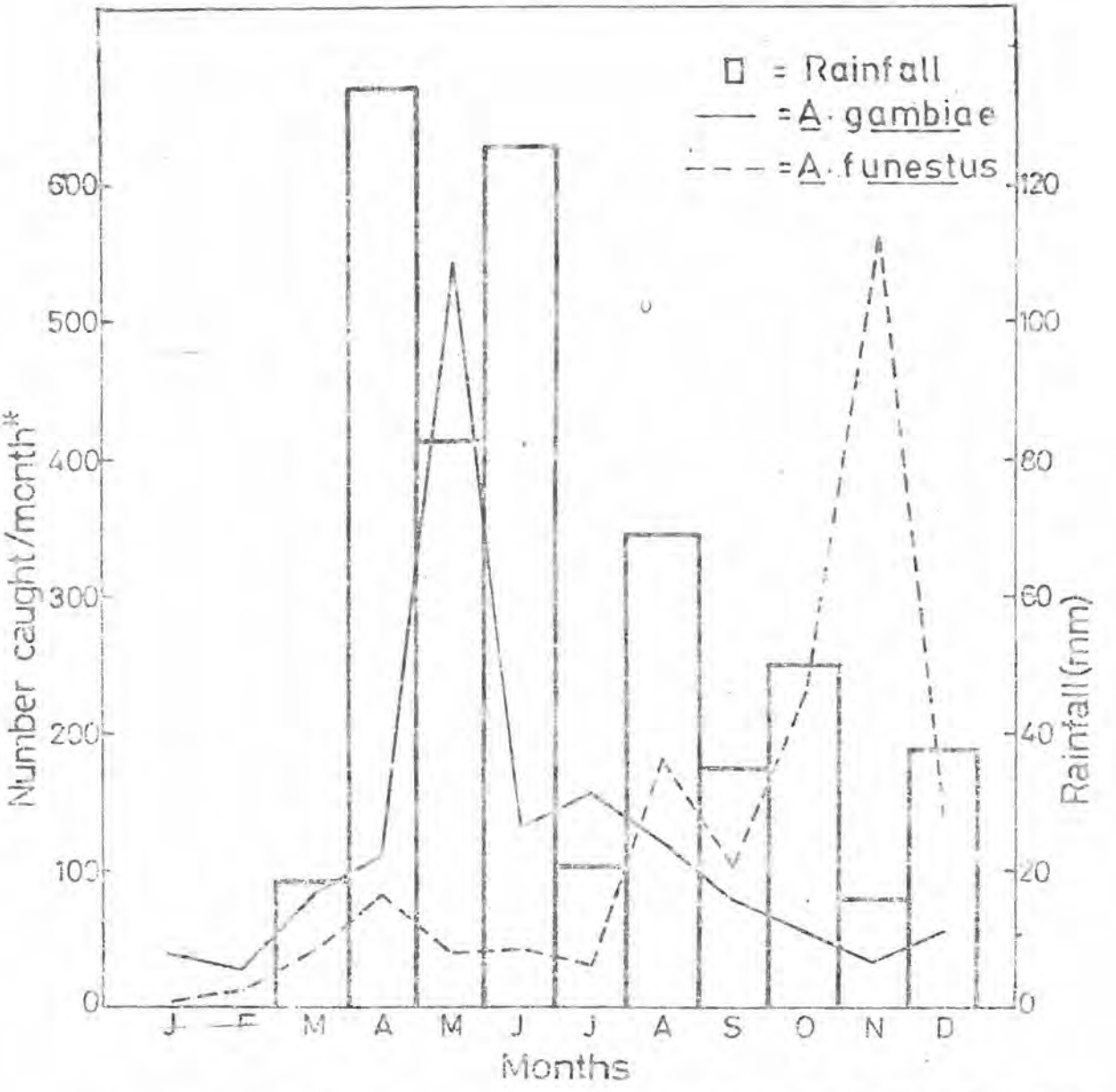


Figure 7: Graph showing the relationship between rainfall, and the number of Anopheles gambiae S.l. and Anopheles funestus collected at Kapkuikui, Loboi. 1986

*Total from 5 houses were pooled

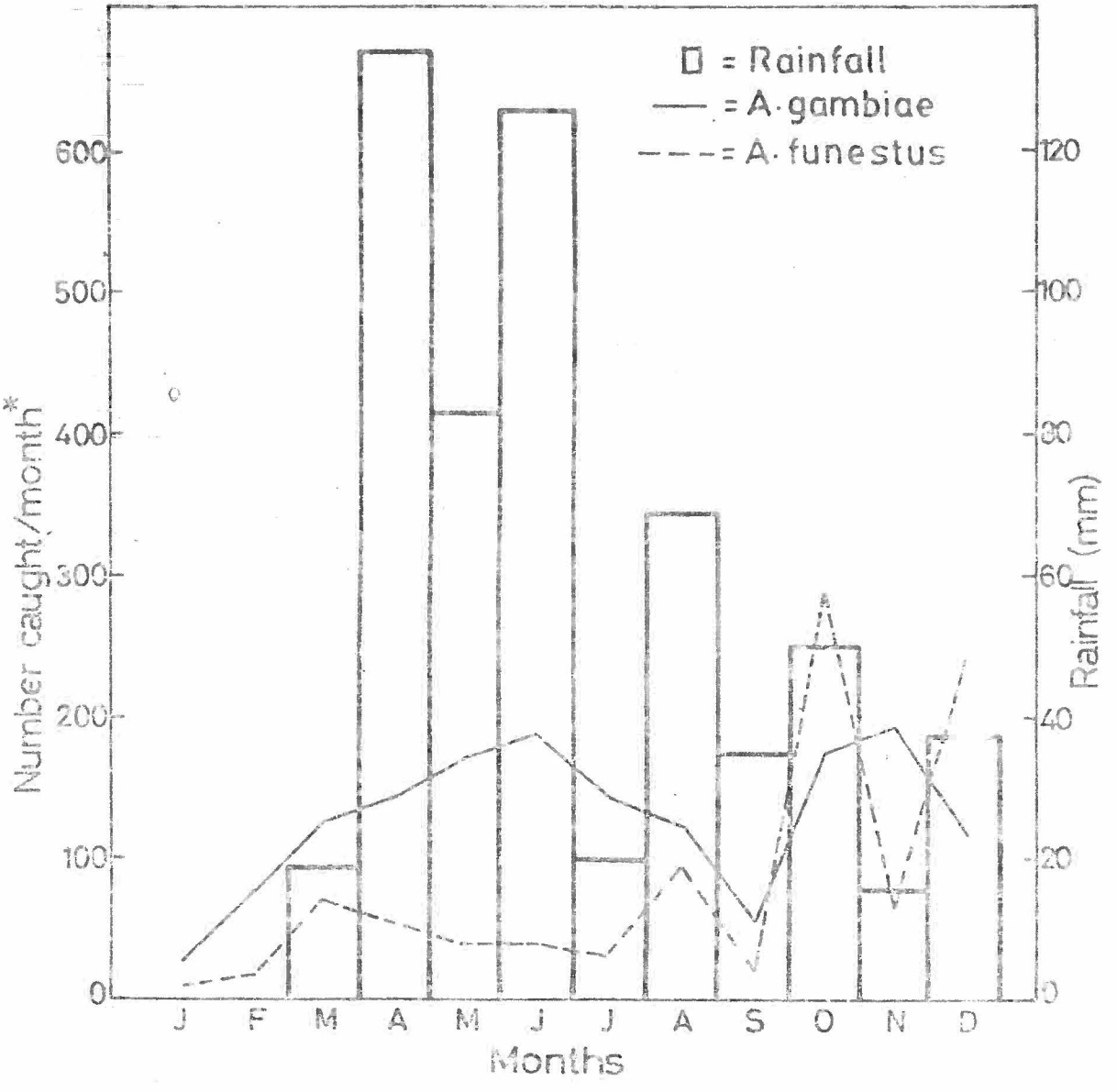


Figure 8: Graph showing the relationship between rainfall and the number of Anopheles gambiae S.l. and Anopheles funestus collected at Tingttiyon, Loboi. 1986

*Total from 5 houses were pooled.

The numbers increased sharply in August at both locations following the decline in rainfall in July. The third peak occurred between October and December. In both locations the first peak in March/April was the lowest and the third in October/December the highest. Each population peak occurred during a month of high rainfall relative to the preceding month (see Figs. 7 & 8). At Kapkuikui, A.funestus was more abundant than A.gambiae during the period August - December, but at Tingttiyon this type of situation occurred only between October to December.

At the Perkerra irrigation scheme, A.gambiae numbers remained low from January to May and then began to increase. The increase was most pronounced, however, from June up to September when the highest population peak was attained. Thereafter there was a sharp drop which continued up to December (Fig.9). Anopheles funestus was comparatively very scanty [illegible] Only 28 of them were collected between January and December 1986. Six of these were caught in February and March (3 each month) and the rest were caught between August and October (see Table 2).

At Endau village sampling for seasonal abundance studies was done from March to December 1986. Anopheles gambiae was first collected in May and its population peak was attained in July (Fig. 10). There was a sharp drop in August, then a slight recovery in September before the final drop which continued up to December. A. funestus was virtually absent in this location, with only a single individual of it collected over the entire sampling period (Fig. 10 and Table 2).

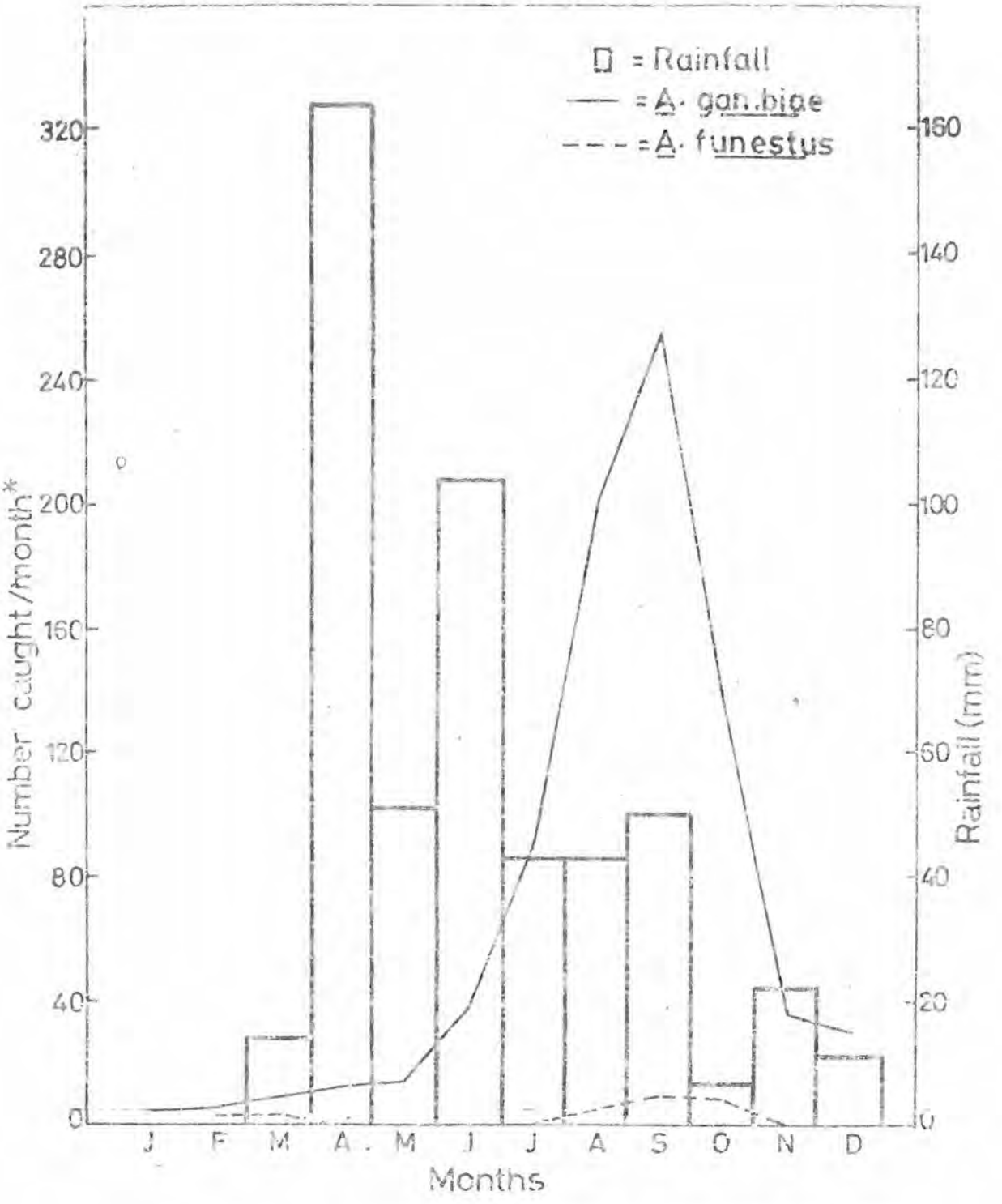


Figure 9: Graph showing the relationship between rainfall, and the numbers of Anopheles gambiae S.l. and Anopheles funestus collected at R1, Perkerra irrigation scheme 1986.

*Total from 5 houses were pooled

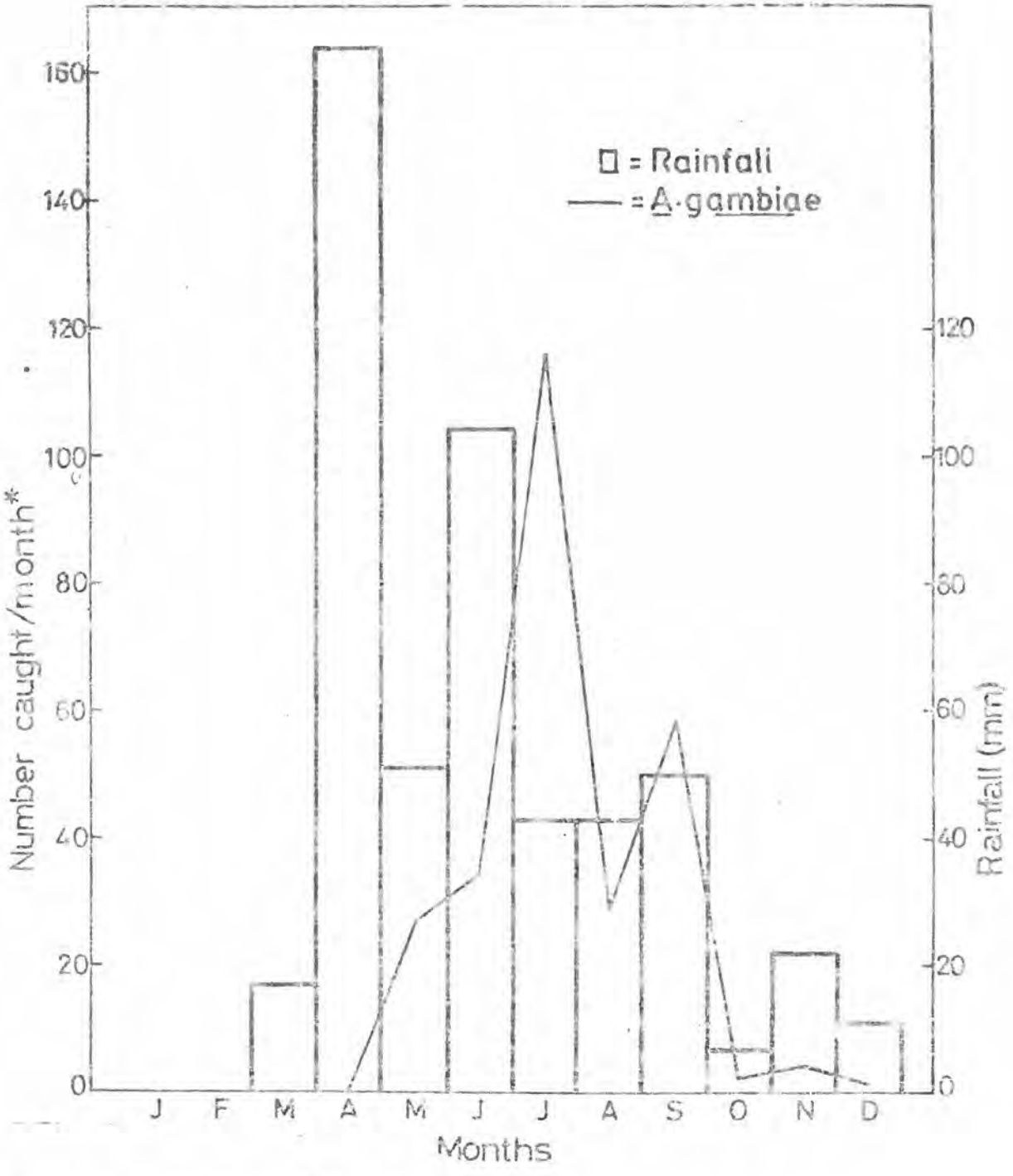


Figure 10: Graph showing relationship between rainfall and the numbers of Anopheles gambiae S.L. collected at Endam village 1986.

*Total from 5 houses were pooled.

C.zombiensis, C.quinquefasciatus and M.africanus were the only culicine mosquitoes present in Loboi and Perkerra locations throughout the year. At Endau, they were very few or totally absent between May and December. All culicine species were pooled for all types of analyses. Their numbers reached a peak in all locations in April, about one month after the onset of the long rains. The numbers declined rapidly during the heavy rains and remained low till the end of the cool dry period. The numbers increased slightly again, October - December (Table 2).

3.3.3 Effect of Climatic Factors on Mosquito Abundance

For the purpose of relating fluctuation in mosquito numbers to seasonal changes in climatic conditions in Marigat, the year was divided into four distinct periods namely:

(i) January-March:- This is the main dry season and is characterized by high temperatures, low relative humidity, strong dusty winds and very little rains.

(ii) April-June: This is the long rainy season characterized by heavy rains, moderate temperatures, high relative humidity and low windspeed.

(iii) July-September: This is the cool, dry period with moderate to low temperatures (especially at night), low windspeed, moderate relative humidity and rainfall

(iv) November-December: Period of the short rains, characterised by little to moderate rainfall, high temperatures, moderate relative humidity

and windspeed. October is a transition month usually characterised by high temperatures, little or no rains and strong dusty winds, like the type just before thelong rains in February-March.

The mean values of these various climatic factors for each period are summarized in Table 3, using the 1986/87 meteorological data recorded at the Perkerra Agricultural Research Station, Marigat. The complete meteorological data for the entire period, Septembe 1985 - December 1987, during which the data for this project were collected are given in Appendix 3.

Table 3: Summary of mean climatic conditions during different times of the year at Marigat in 1986 - 1987*

Period	Rainfall (mm).	Temperature ^{0}C Max.	Min.	Relative Humidity & Windspeed A.M.	P.M.	(mph).
Jan.-Mar.	5.6	35.0	18.0	48.0	30.3	69.3
	36.6	34.4	18.2	65.0	42.9	67.9
Apr.-Jun.	106.0	31.7	18.2	76.1	48.8	41.4
	120.7	31.4	15.8	64.8	41.5	36.5
October	6.5	32.6	17.2	58.0	35.7	68.7
	7.4	36.3	19.1	46.4	29.5	66.5
Nov.-Dec.	16.7	34.9	18.1	50.4	50.4	56.7
	40.0	34.2	18.2	56.8	38.2	55.9

* Lower figures are for 1987.

3.3.3.1 Effect of Rainfall on Mosquito Abundance

The relationship between rainfall and the relative abundance of the two main malaria vectors in the Loboi swamp area, A.gambiae and funestus, are shown in Figs. 7 and 8. The steep increase in A.gambiae at Kapkuikui occurred in May, one month after the rainfall peak in April. There was also a slight increase in numbers in July, following the heavy rains in June. For A.funestus in this location the first of the three population peaks coincided with the April rainfall peak, following initial low rains in March. The second and third peaks in August and November similarly followed relatively

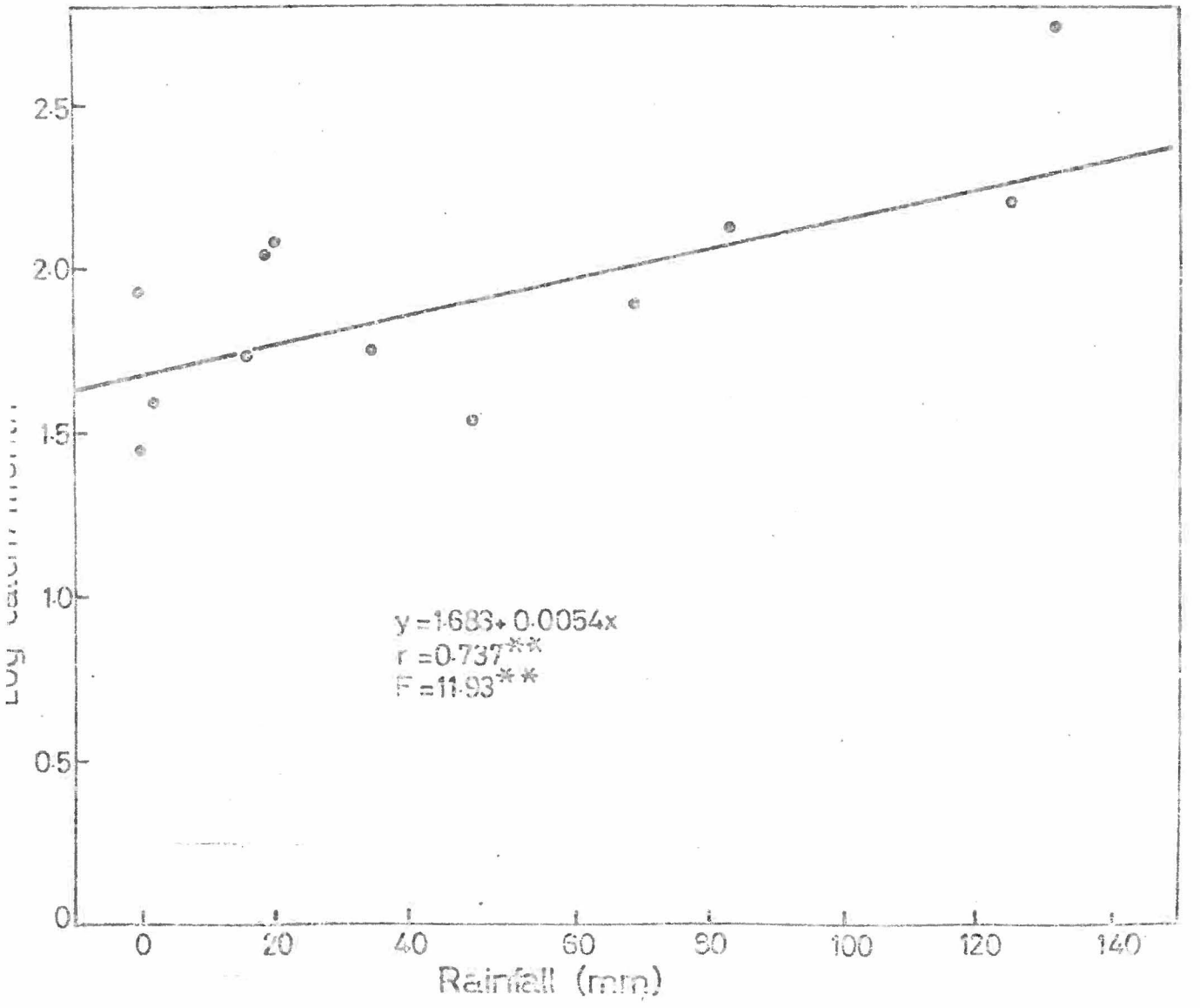


Figure 11: Scatter diagram showing strong positive correlation between monthly catches of Anopheles gambiae S.l. and rainfall of the preceeding months at Kapkuikui, Koboi 1986

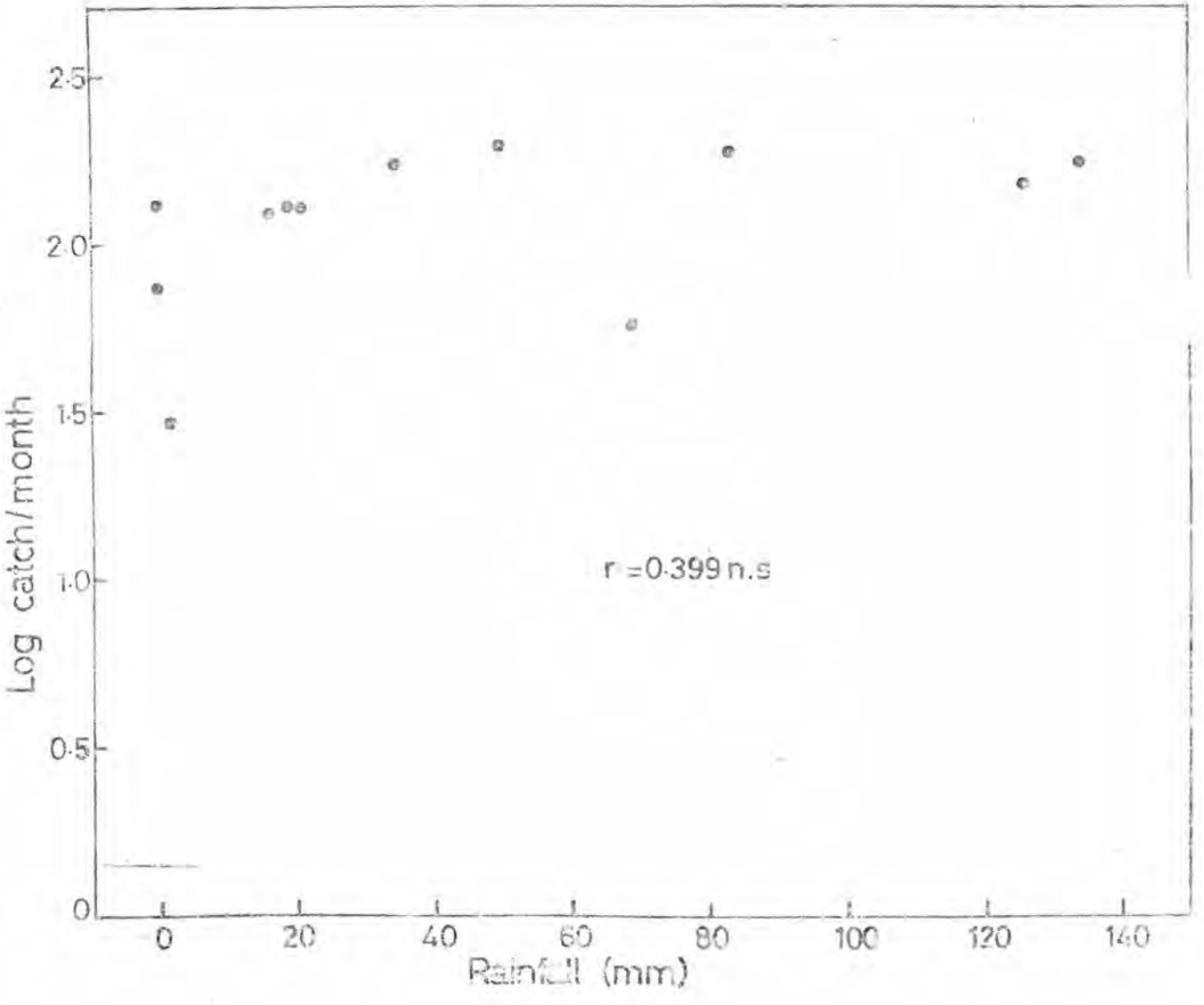


Figure 12: Scatter diagram showing non-significant positive correlation between monthly catches of Anopheles gambiae S.l. and rainfall of the preceding months at Tingttiyon, Loboi 1986

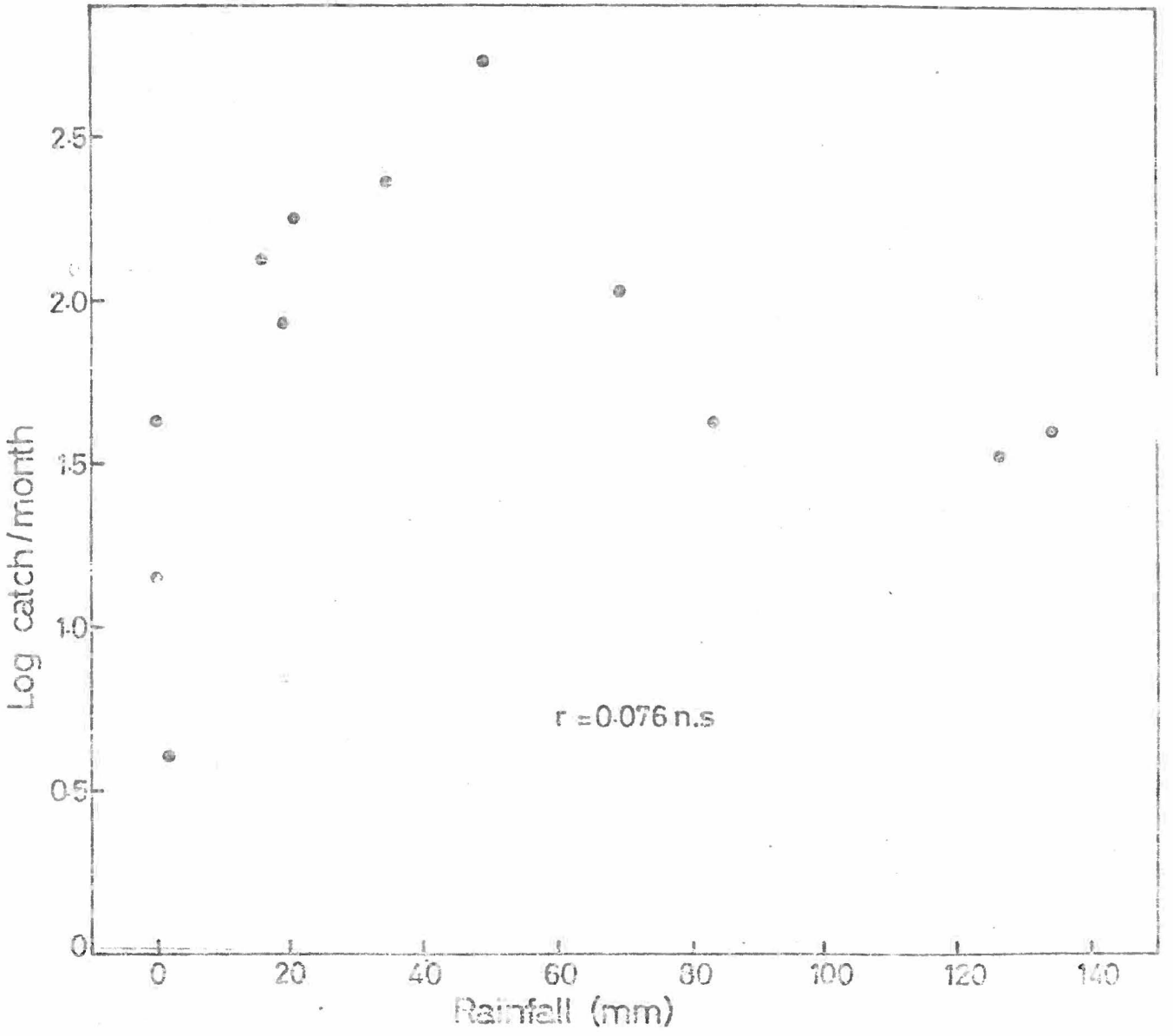


Figure 13: Scatter diagram showing absence of correlation between monthly catches of Anopheles funestus and rainfall of the preceeding months at Kapkuikui, Lobei 1986

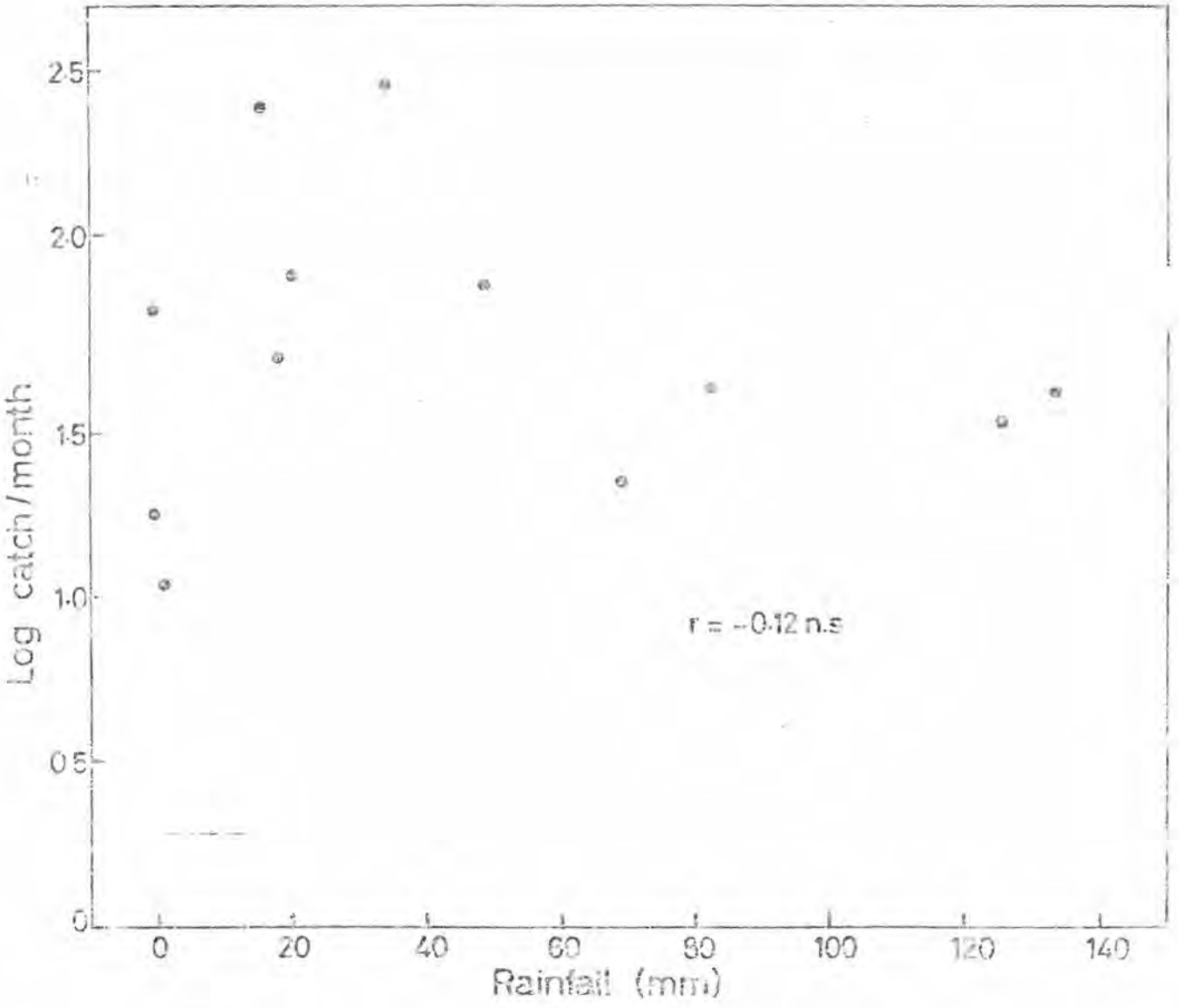


Figure 14: Scatter diagram showing absence of correlation between monthly catches of Anopheles funestus and rainfall of the preceeding months at Tingttyon, Loboi 1986

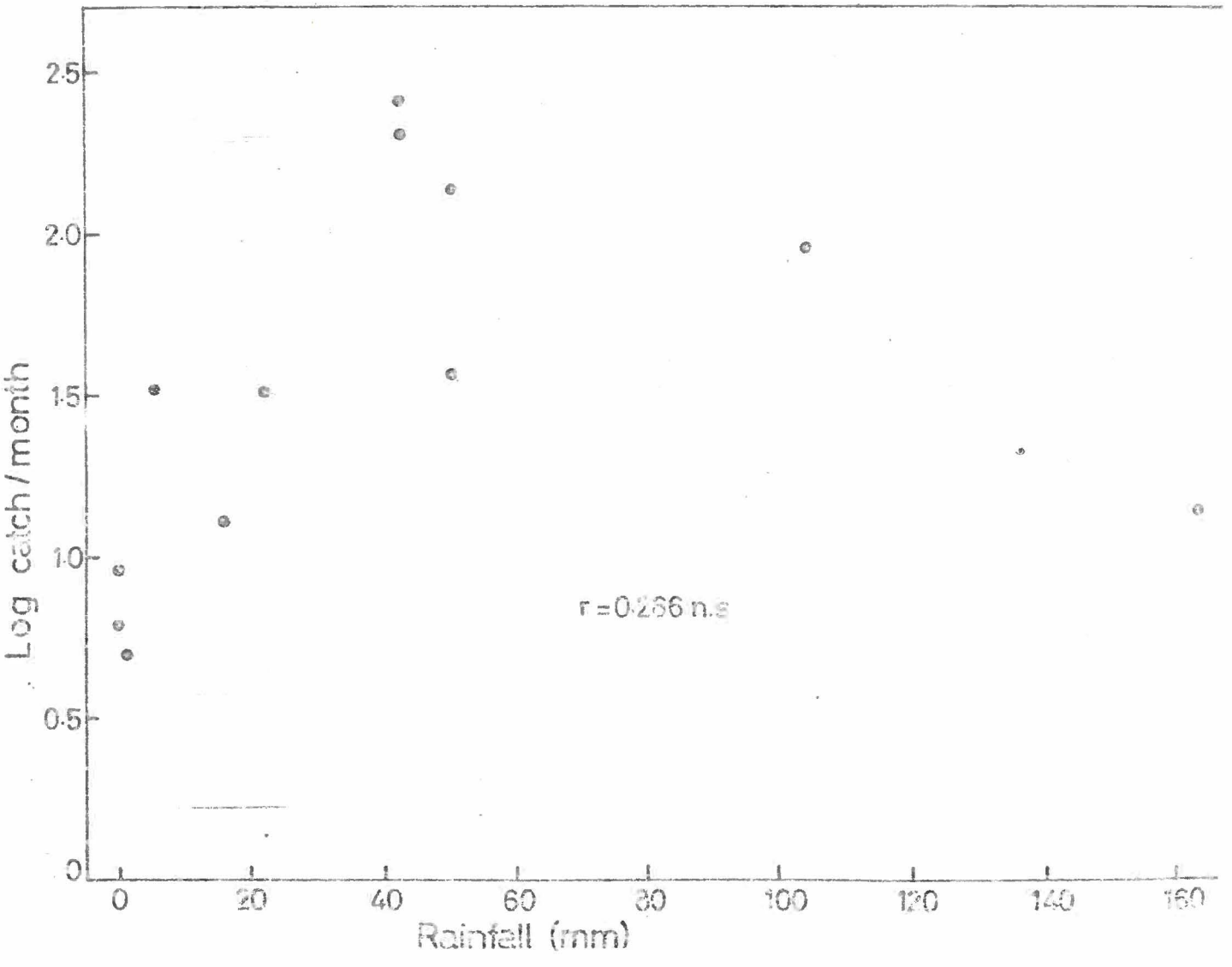


Figure 15: Scatter diagram showing absence of correlation between monthly catches of Anopheles gambiae S.l. and rainfall of the preceeding months at R1, Perkerra irrigation scheme 1986.

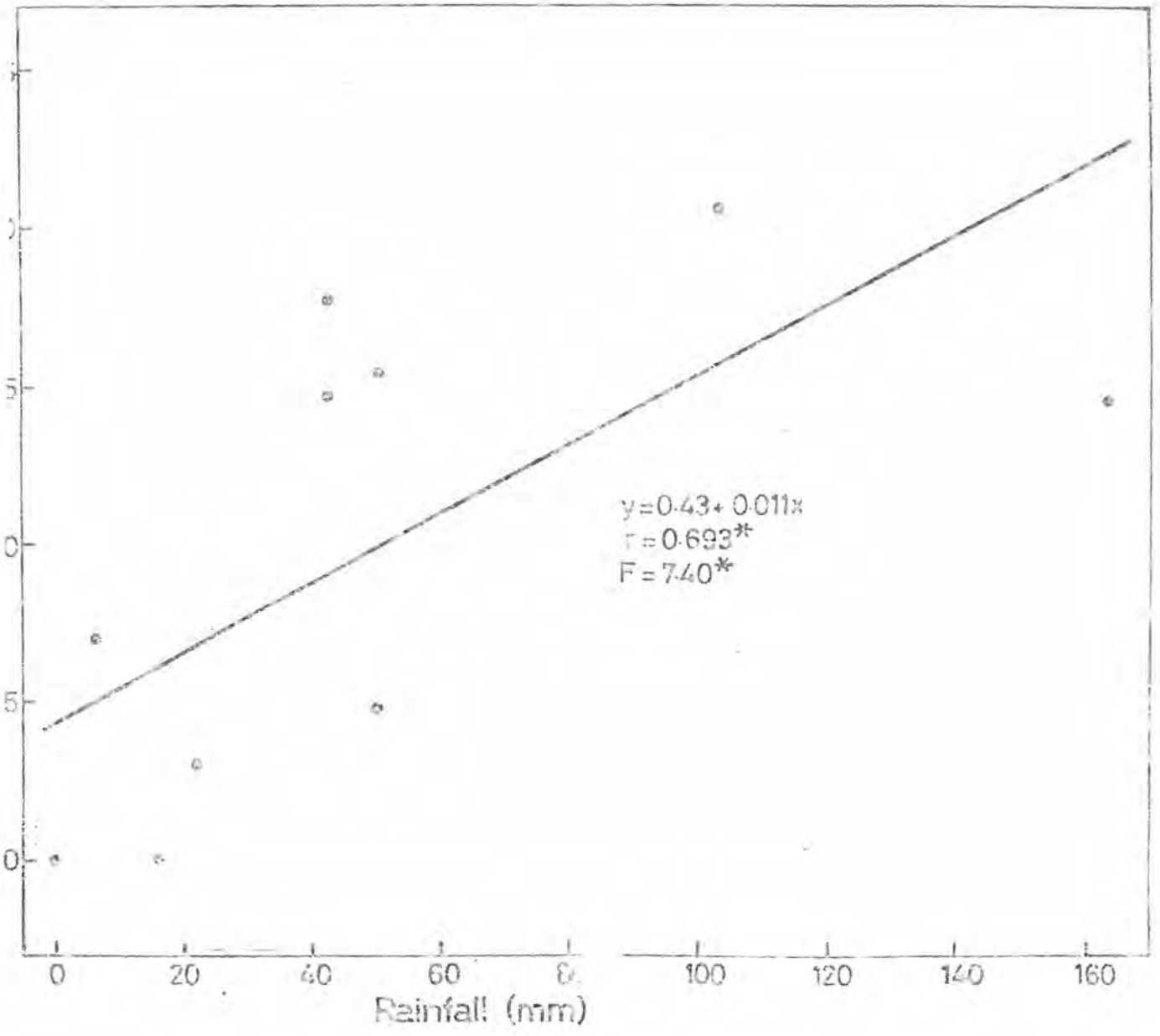


Figure 16: Scatter diagram showing positive correlation between monthly catches of Anopheles gambiae S.l. and rainfall of the preceeding months at Ndau village, 1986

low rainfalls in the preceeding months of July and Semptember respectively (Figure 7). At Tingttiyon, the steady increase in numbers of A.gambiae reached its maximum in June, two months after the hHigher of the two rainfall peaks (in April) and coincidental with the second lower one. For A.funestus the first of the three population peaks occurred in March, the first month of the rainy season. The second and third peaks in August and October followed relatively low rainfalls in July and September respectively as was the case in Kapkuikui (Fig. 8)

Scatter diagram (Fig. 11) shows that there was a strong positive correclation between rainfall of the preceeding month and A. gambiae catches at Kapkuikui. This relationship was highly significant ($r = 0.737$, $F = 11.93$, $p < 0.01$). The correlation between rainfall of previous month and A.gambiae catches at Tingttiyon was not significant ($r = 0.399$, $p > 0.05$, Fig. 12). There was also no correlation between rainfall of previous month and A.funestus monthly catches at both locations as shown in Figs 13 and 14 ($r = 0.076$ and $r = -0.12$), for Kapkuikui and Tingttiyon respectively.

The situation at the Perkerra irrigation scheme was entirely different. The first steep increase in numbers occurred in June, two months after the first rainfall peak. But mosquito population peak was not attained until September, three months after the end of the long rains (Fig. 9). There was only a weak positive correlation between rainfall and A.gambiae monthly catches which was non-significant at 5% ($r = 0.22$, Fig. 15).

At Lndau village, no A.gambiae mosquitoes were collected between March and April, probably due to no rainfalls in the preceeding months of January-February. A.gambiae was first collected in May and the population increased steeply until the peak was attained in July, one month after the second rainfall peak (Fig. 10). There was a significant positive correlation between rainfall of previous months and A.gambiae monthly catches ($r = 0.693$, $F = 7.40$, $p < 0.05$) as shown in Fig. 16.

3.3.3.2 Effect of Temperature and Relative Humidity on Mosquito Abundance

The seasonal variations of the two major Anopheles species in Marigat relative to changes in temperature and relative humidity are shown in Figs. 17-20. Temperature and relative humidity are considered together here so as to highlight the close inverse relationship between them. At Kapkuikui the population peak for A.gambiae was reached between April and July which corresponded to the period of the year with the lowest temperatures (Fig. 17). That is, there was an inverse relationship or negative correlation between temperatures and numbers of mosquitoes collected. As temperatures fell with the onset of the rains in March, mosquito numbers rose sharply. When the temperatures again began to rise after July, mosquito numbers dropped abruptly. This negative correlation between mosquito numbers and temperature was significant at 5% ($r = -0.636$, $F = 6.128$,

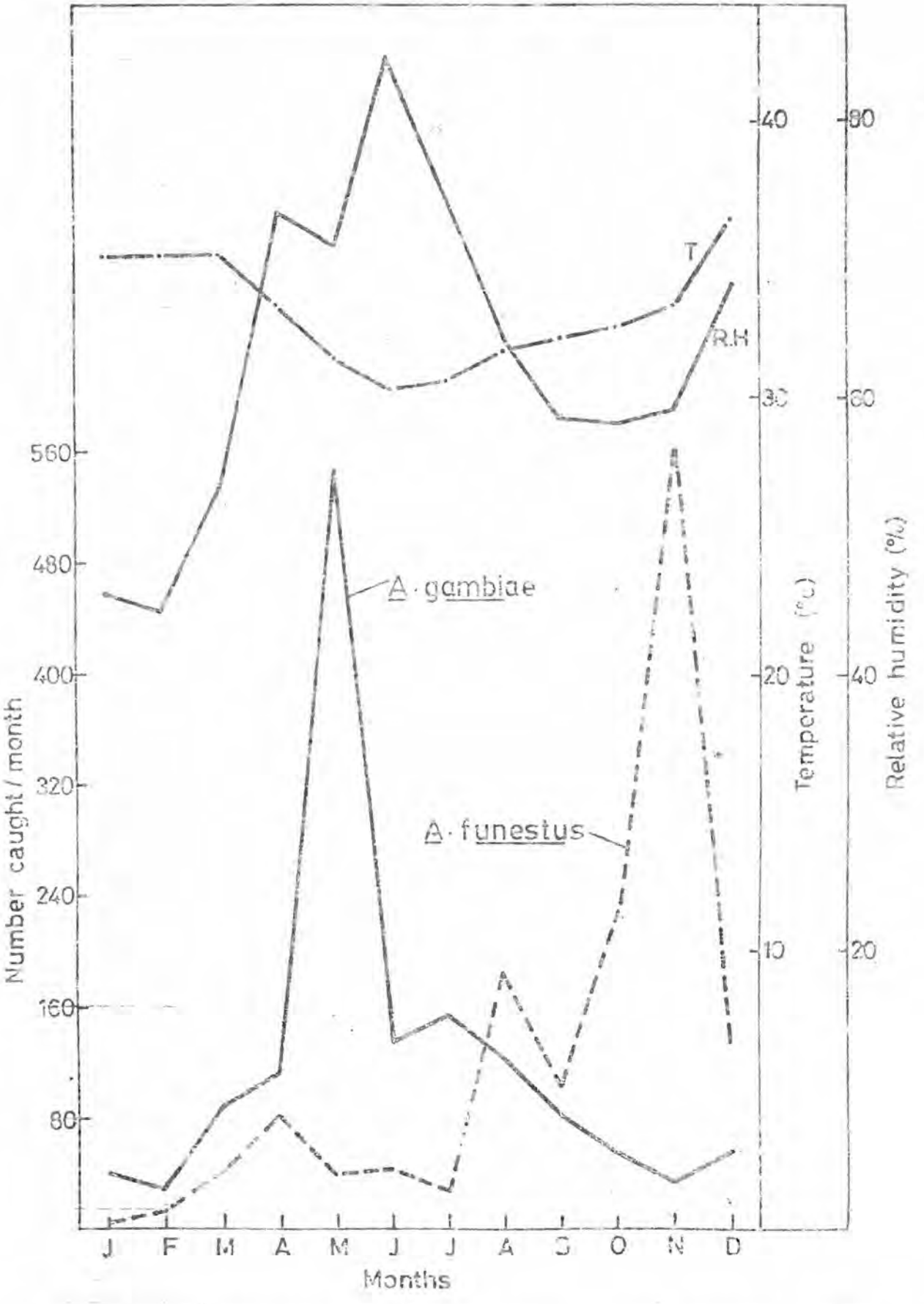


Figure 17: Relationship between temperature, relative humidity and the numbers of Anopheles gambiae S.l. and Anopheles funestus collected at Kapkuikui, Loboi. 1986

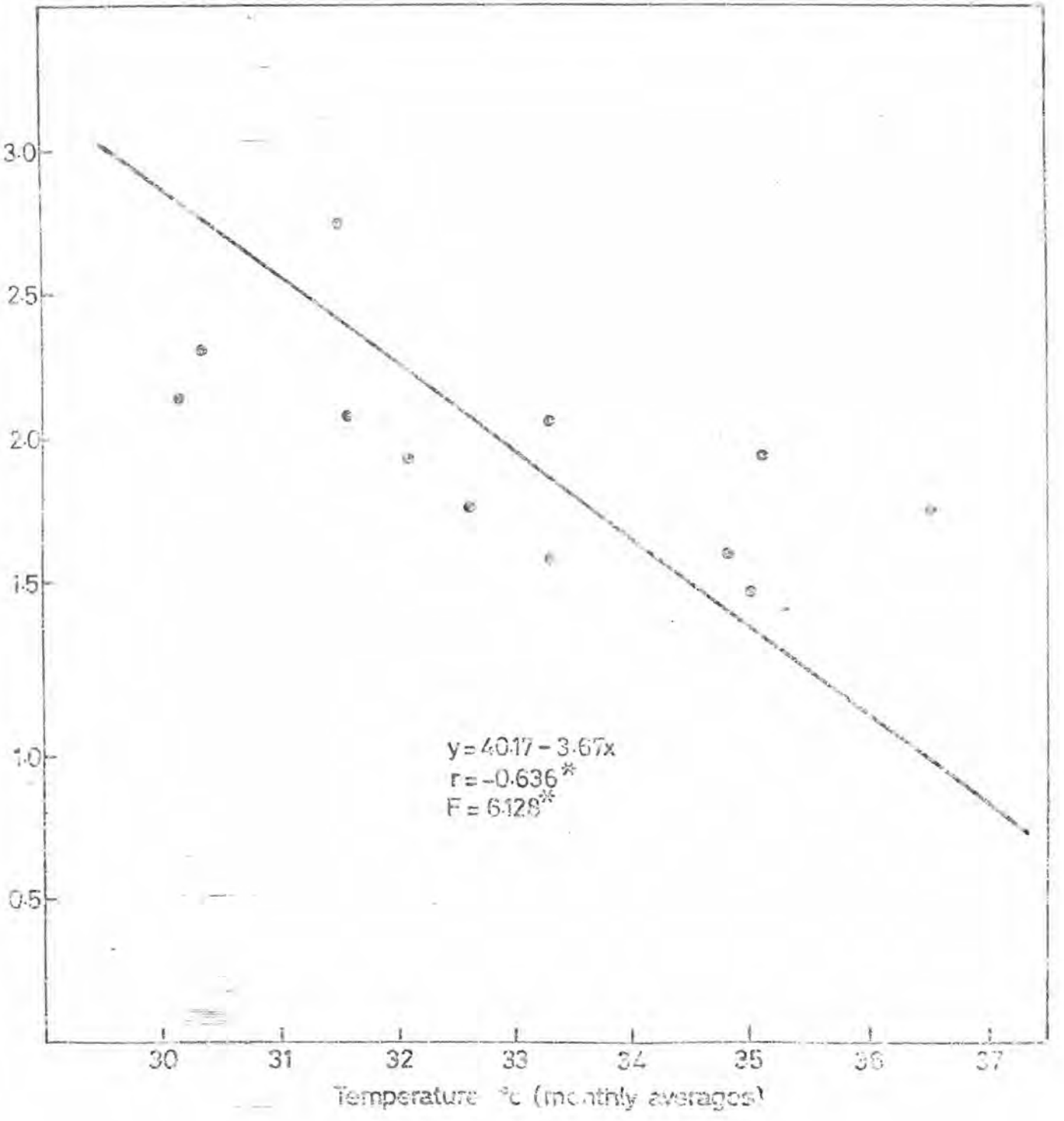


Figure 18: Scatter diagram showing strong negative correlation between monthly catches of Anopheles gambiae S.l. and temperature at Kapkurikui, Loboi. 1986

$p < 0.05$) as shown in Fig. 18. Since temperature is inversely proportional to relative humidity, Anopheles gambiae catches showed a strong positive correlation to relative humidity at this location. The highest numbers of A.gambiae were collected between April and July when R.H. was highest (Fig. 17). This correlation was highly significant ($r = 0.674$ $F = 7.49$, $p < 0.01$) as shown in the scatter diagram (Fig. 19).

For A.funestus, the three population peaks in April, August and November corresponded to periods of moderate temperatures and relative humidities. The highest numbers of this species were collected between October and December, a period of high temperatures and low relative humidity.

The pattern of seasonal distribution of A.gambiae at Tingttiyon and Endau with respect to changes in temperature and relative humidity was similar to that at Kapkuikui. Thus the peak populations were attained between May and July when temperatures were lowest and relative humidities highest (Figs. 20 and 21). For A.funestus at Tingttiyon, the highest numbers were collected between October and December when temperatures were relatively high and relative humidity low (Fig. 20).

At Perkerra, unlike the Loboi and Endau locations, A.gambiae peak populations did not coincide with the period of lowest temperatures and highest relative humidities, just as it did not coincide with the period of maximum rainfalls (Fig. 22)

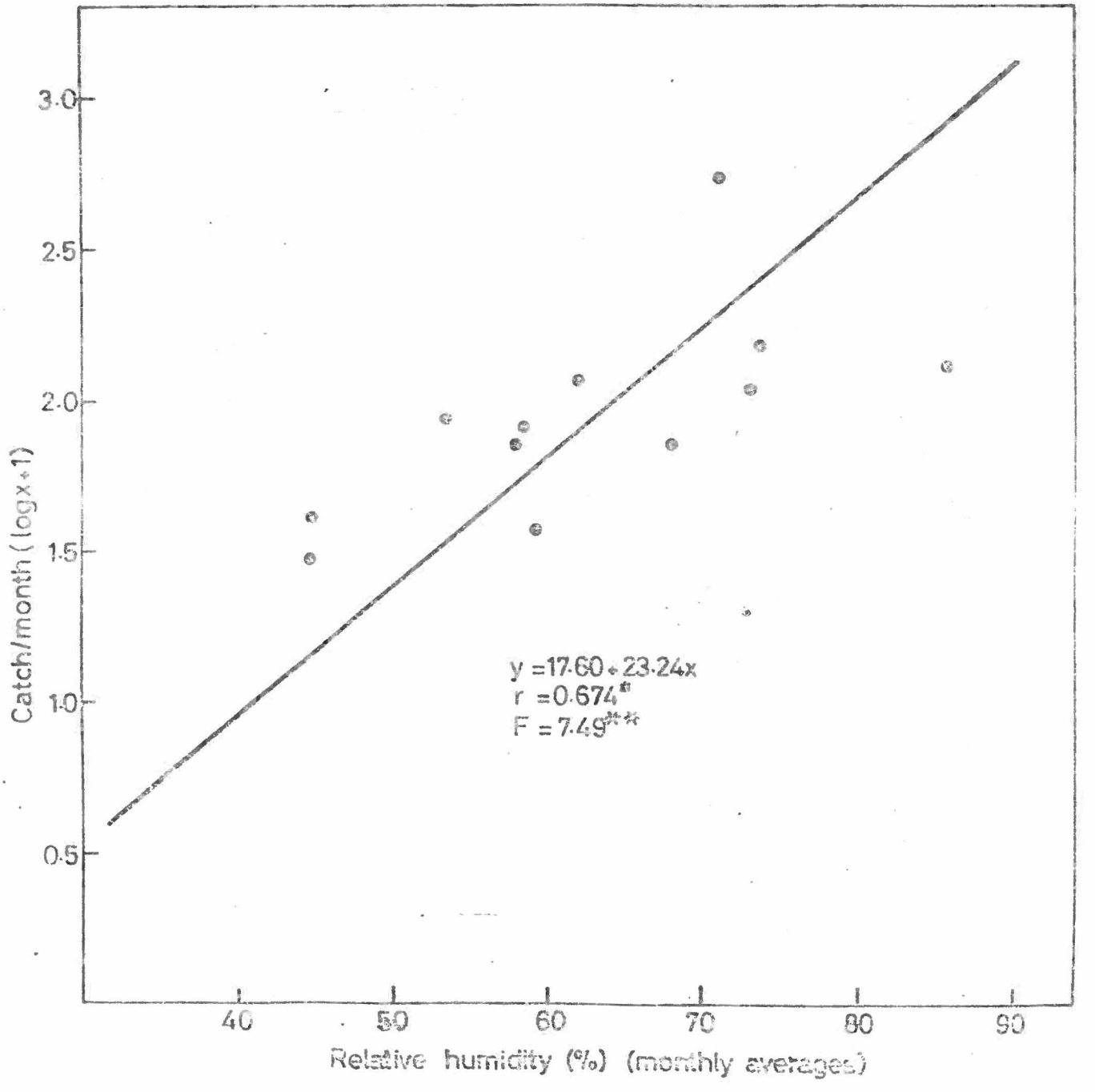


Figure 19: Scatter diagram showing strong positive correlation between monthly catches of Anopheles gambiae S.l. and relative humidity at Kapkuikui, Loboi. 1986

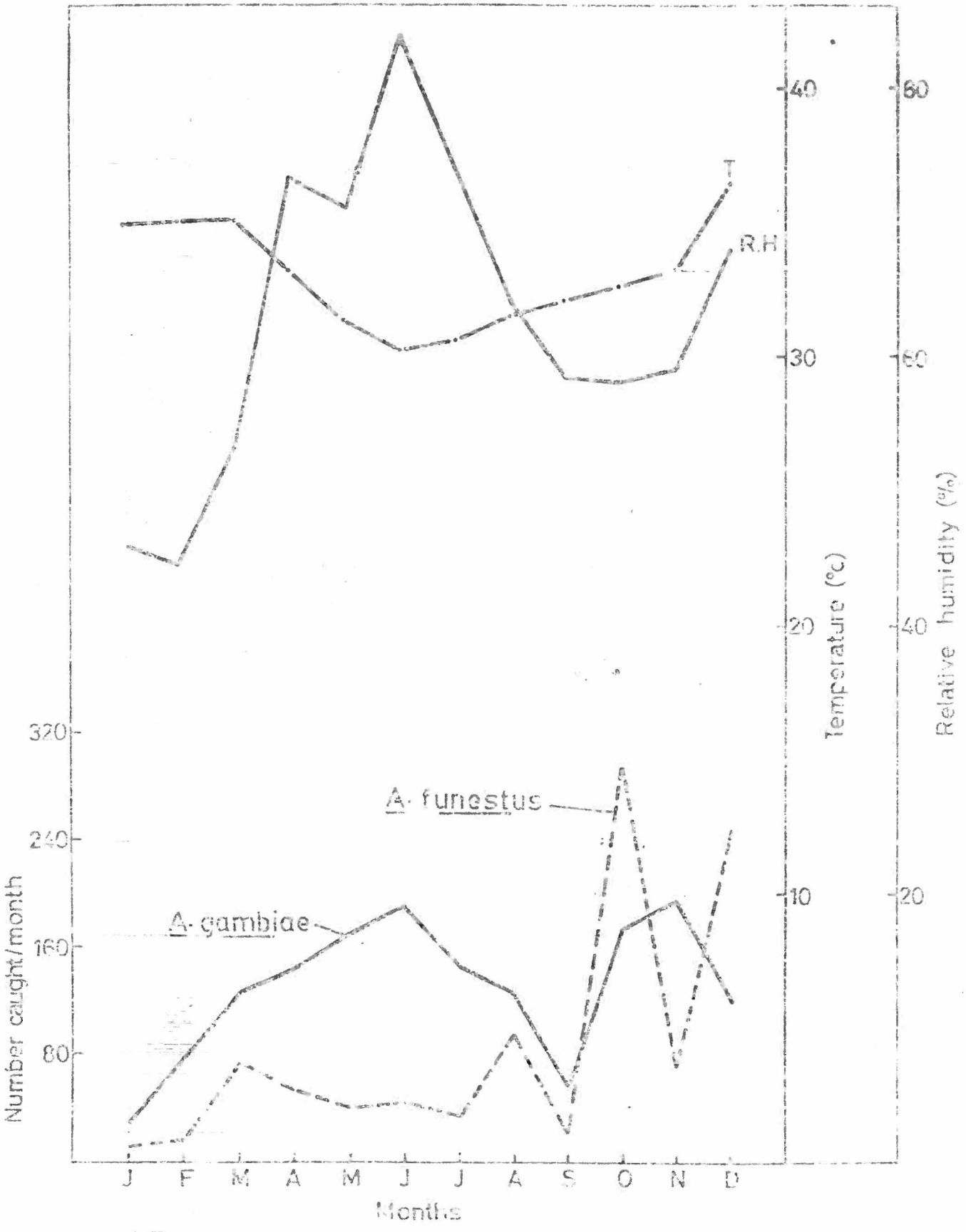


Figure 20: Relationship between temperature, relative humidity and the numbers of Anopheles gambiae S.l. and Anopheles funestus at Tingttiyon, Loboi. 1986

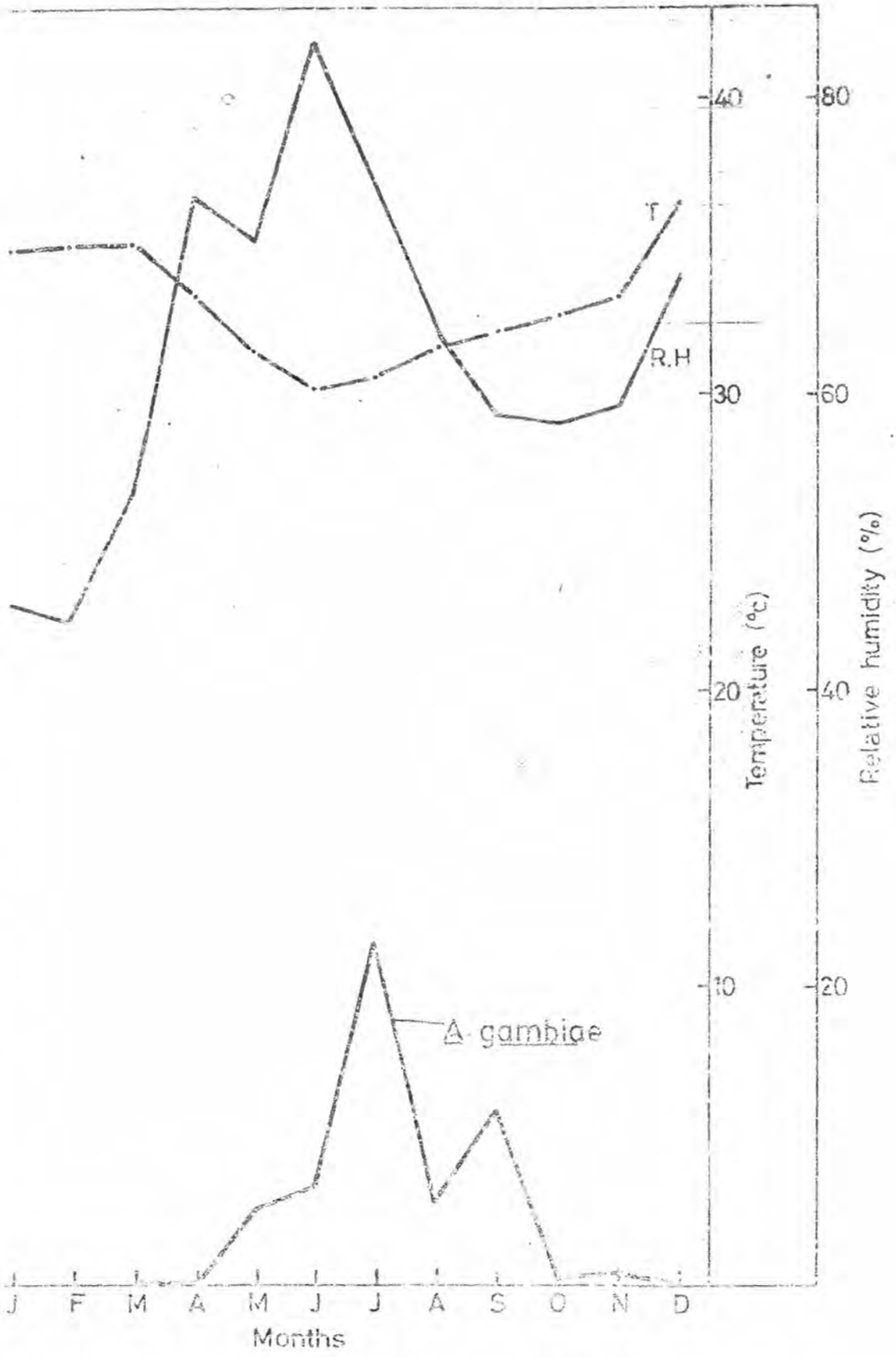


Figure 21: Relationship between temperature, relative humidity and numbers of Anopheles gambiae s.l. collected at Endau village. 1990

3.3.3.3. Effect of Windspeed on Mosquito Abundance

The relationship between windspeed and the seasonal relative abundance of the two major anopheline species are illustrated by Figs. 23 and 24 for Loboi and Fig. 25 for Perkerra. The highest windspeed occurred between January and March which was also the driest and hottest part of the year. Wind velocity was also very high in October. As wind velocity decreased as from April, A.gambiae numbers increased, reaching their maximum in May at Kapkuikui and in June at Tingttiyon. The lowest wind speeds prevailed between June and August. Thus there was an inverse relationship between wind velocity and the numbers of A.gambiae collected. This negative correlation was significant at Kapkuikui ($r = -0.689$, $F = 8.14$, $p<0.01$) as shown in Fig. 24. For A.funestus in these two locations the population peaks coincided with periods of high wind velocities between October and December. Again the strong correlation between A.gambiae catches and windspeed was probably due to the cross-correlation between the latter and rainfall.

At Perkerra the period of very high wind between January and March was marked by low A.gambiae catches. Catches remained low upto June despite rapid drops in wind velocity between April and June (Fig.25). The highest numbers of mosquitoes were collected between July and September, corresponding to a period of moderate wind velocities. At Endau village the highest A.gambiae catches were in July, the month with the lowest wind velocity.

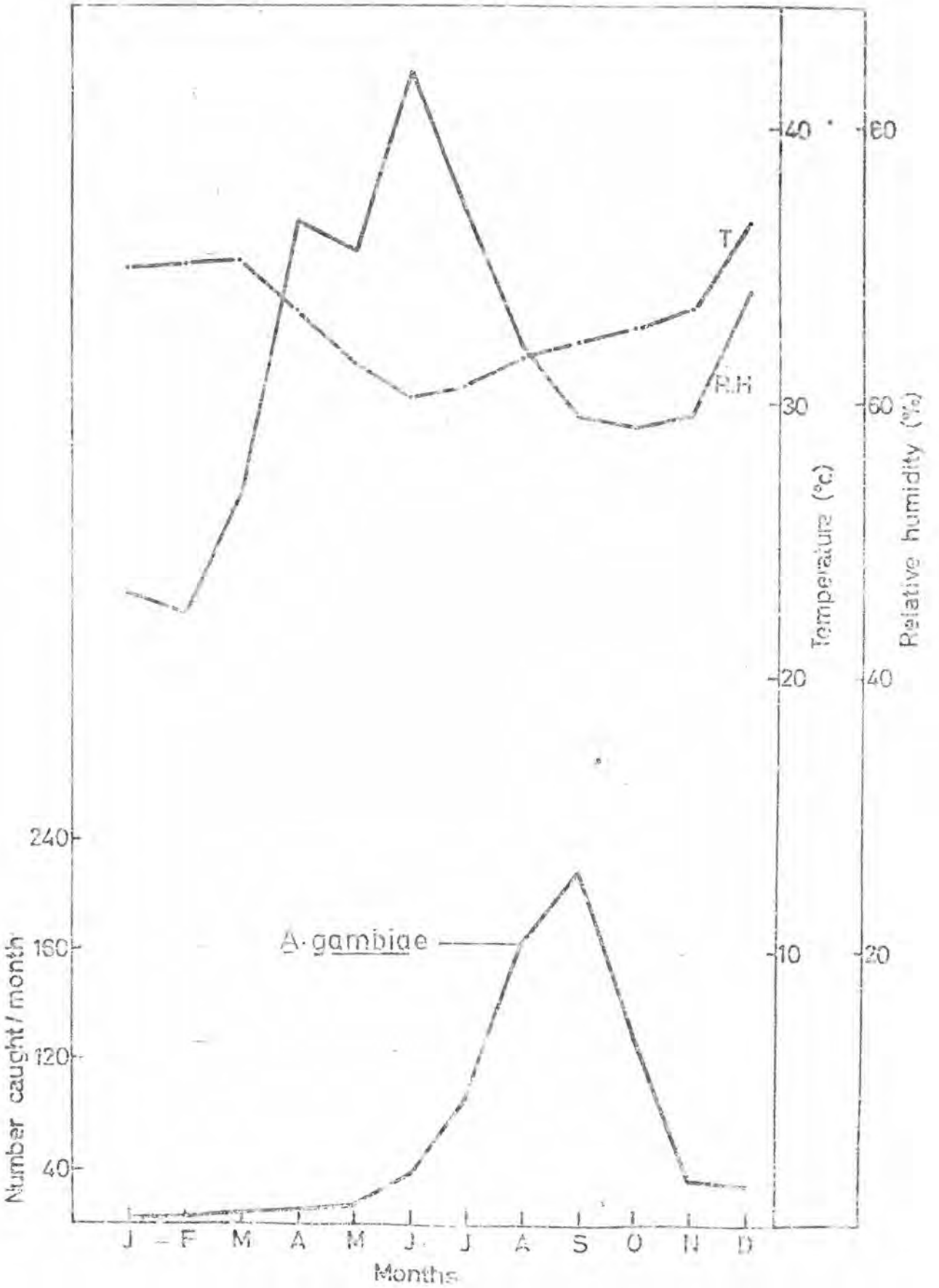


Figure 22: Relationship between temperature, relative humidity and the numbers of Anopheles gambiae collected at R1, Pedkerra irrigation scheme, 1986

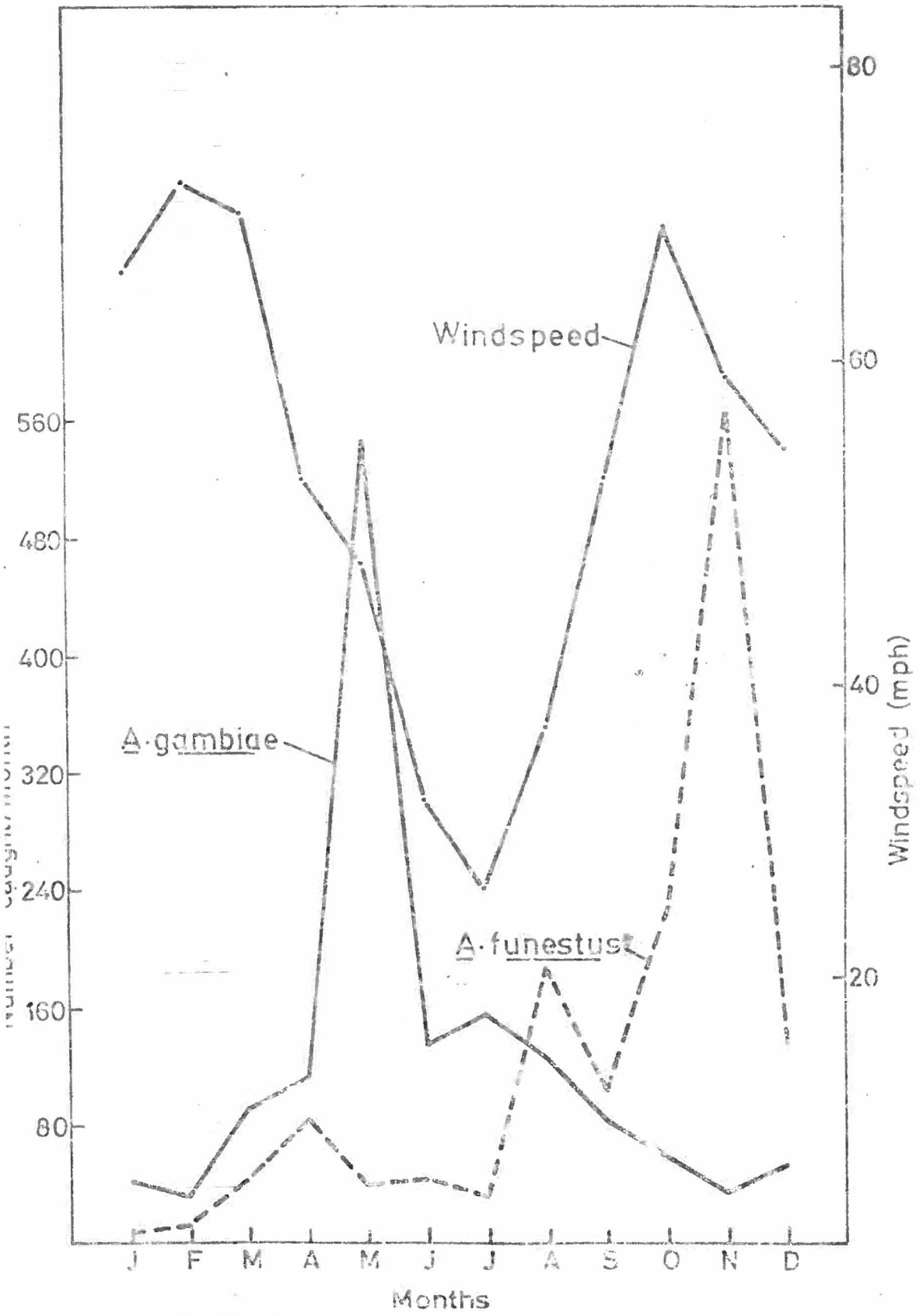


Figure 23: Relationship between windspeed and the numbers of Anopheles gambiae and Anopheles funestus collected at Kapkuikui Eldoret. 1986

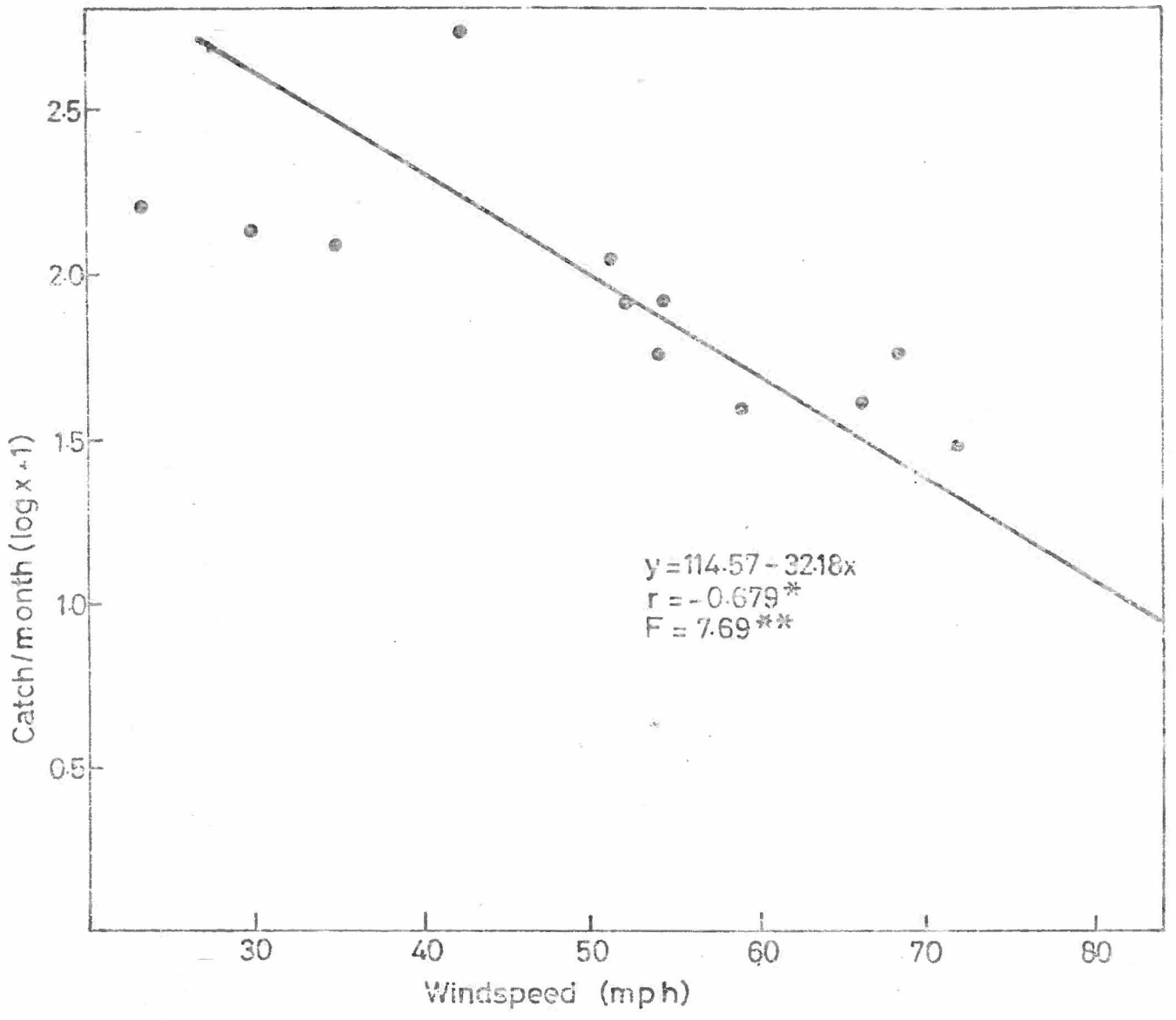


Figure 24: Scatter diagram showing strong negative correlation between monthly catches of Anopheles gambiae S.l. and windspeed at Kapkuikui Loboi.

Thus in this location maximum mosquito catches coincided with optimum windspeed condition as was the case with the other climatic conditions already discussed.

The relationships of these climatic conditions, rainfall, temperature, relative humidity and windspeed, with the relative abundance of the two major malaria vectors in the study area are summarized in Tables 4 A and B. Table 4A gives the values of the coefficient of correlation, r, between the climatic factors and the corresponding mosquito catches as well as the F-ratios which indicate their levels of significance. Table 4B gives the values of r^2 and $1-r^2$. According to Snedecor and Cochran (1980) r^2 represents the estimated proportion of the variance of mosquito catches, Y, which could be attributed to its linear regression on the corresponding climatic factor, x, while $1-r^2$ is the proportion free of it. It can be seen that at Endau the variations of mosquito catches associated with rainfall, temperature, relative humidity and windspeed was 0.5, 0.65, 0.11 and 0.61 respectively while at Kapkuikui, Loboi it was 0.34, 0.40, 0.45 and 0.46 respectively. In all the cases where r was nonsignificant, there was virtually no association between the two variables.

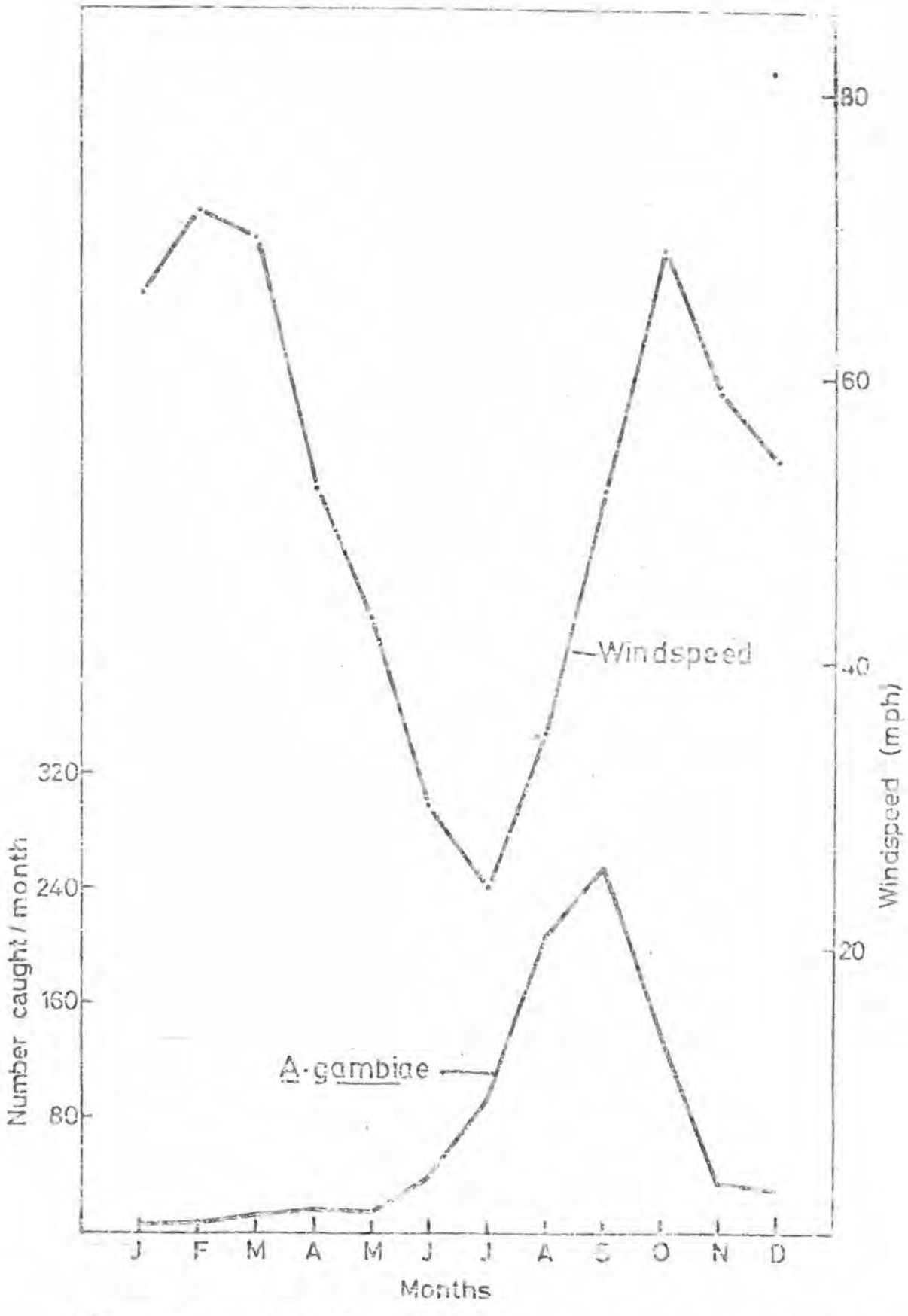


Figure 25: Relationship between windspeed and numbers of Anopheles gambiae collected at R1, Perkerra irrigation scheme. 1985

Table 4A: A Summary of the relationship between Climatic Factors and Relative Abundance of *Anopheles* mosquitoes.

LOCATION	SPECIES	CLIMATIC CORRELATION ANALYSIS FACTOR	Type	r Value	F-ratio	Level of significance
Kapkuikui (Löboi)	*A. gambiae*	Rainfall	+ve	+0.583	5.17	*
	"	Temp.	-ve	-0.636	6.128	*
	"	R.H.	+ve	+0.674	7.49	**
	"	Windspeed	-ve	-0.679	7.69	**
	A. funestus	Rainfall	-ve	-0.053	-	N.S.
	"	Temp.	-ve	-0.094	-	N.S.
	"	R.H.	+ve	+0.302	-	N.S.
	"	Windspeed	-ve	-0.033	-	N.S.
Tingttiyon (Loboi)	*A. gambiae*	Rainfall	+ve	+0.49	-	N.S.
	"	Temp.	-ve	-0.36	-	N.S.
	"	R.H.	+ve	+0.658	6.86	**
	"	Windspeed	-ve	-0.303	-	N.S.
	A. funestus	Rainfall	-ve	-0.053	-	N.S.
	"	Temp.	+ve	+0.126	-	N.S.
	"	R.H.	+ve	+0.039	-	N.S.
	"	Windspeed	+ve	+0.05	-	N.S.
RI PERKERRA	*A. gambiae*	Rainfall	+ve	+0.25	-	N.S.
		Temp.	-ve	-0.548	-	N.S.
		R.H.	+ve	+0.359	-	N.S.
		Windspeed	-ve	-0.442	-	N.S.
ENDAU		Rainfall	+ve	+0.704	7.97	**
		Temp	-ve	-0.805	12.91	***
		R.H.	+ve	+0.33	-	N.S.
		Windspeed	-ve	-0.781	10.96	**

*,**,*** = significant at 0.05, 0.025 and 0.01 respectively

N.S. = Non-significant

Table 43: Estimated proportions of the variance of Mosquito Catches associated and not associated with Climatic Factors in a linear regression.

LOCATION	SPECIES	CLIMATIC FACTOR	CORRELATION ANALYSIS Type	corr. coeff.r	Assoc. r^2	Not Assoc. $1-r^2$
	A. gambiae	Rainfall	+ve	+0.583	0.34	0.66
Kapkuikui	"	Temp.	-ve	-0.636	0.40	0.60
(Loboi)	"	R.H.	+ve	+0.674	0.45	0.55
	"	Windspeed	-ve	-0.679	0.46	0.54
	A. funestus	Rainfall	-ve	-0.053	0.003	0.997
	"	Temp.	-ve	-0.094	0.009	0.991
	"	R.H.	+ve	+0.302	0.091	0.908
	"	Windspeed	-ve	-0.033	0.001	0.999
Tinattiyon	A. gambiae	Rainfall	+ve	+0.49	0.24	0.76
(Loboi)	"	Temp.	-ve	-0.36	0.13	0.87
	"	R.H.	+ve	+0.658	0.43	0.57
	"	Windspeed	-ve	-0.503	0.25	0.75
	A. funestus	Rainfall	-ve	-0.053	0.003	0.997
	"	Temp.	+ve	+0.126	0.02	0.98
	"	R.H.	+ve	+0.089	0.008	0.992
	"	Windspeed	+ve	+0.05	0.003	0.997
Rl	A. gambiae	Rainfall	+ve	+0.25	0.06	0.94
PERKERRA		Temp.	-ve	-0.548	0.30	0.70
		R.H.	+ve	+0.359	0.13	0.87
		Windspeed	-ve	-0.442	0.20	0.80
ENDAU		Rainfall	+ve	+0.704	0.50	0.50
		Temp	-ve	-0.805	0.65	0.35
		R.H.	+ve	+0.33	0.11	0.89
		Windspeed	-ve	-0.761	0.61	0.39

Corr. coeff. = correlation coefficient

Assoc. = Associated

3.4 Discussion

3.4.1 Species Diversity and Distribution

Marigat division of Baringo district, Kenya is semi-arid, dry, dusty and sparsely forested, with an annual rainfall of about 600mm. Despite this dry climate, there is a great diversity of mosquito species in the area and breeding is maintained all round the year in some permanent bodies of water. The most important of these with respect to mosquito breeding were found to be the Loboi swamp and the Perkerra irrigation scheme. Seventeen species were collected and identified in the course of this study, all of which were found to breed in the Loboi swamp while five were found to breed in the irrigation scheme. Other permanent bodies of water in the area included the Chemeron artificial lake and lakes Bogoria and Baringo. Mosquito breeding was very minimal at Chemeron probably because it has only been created in 1985 and the water level was still fluctuating greatly. No mosquito larvae were collected from lake Bogoria during two years of sampling. This was probably due to the high alkalinity and salinity of the lake water (mean pH = 10.15; percentage salinity = 2.8 (equivalent of 105% seawater), (McCall 1967). A. gambiae and A. funestus which were the most abundant species in the area are known to have lower salinity tolerances of 2.0 and 0.73 (equivalent of 75% and 27% seawater) respectively, (Gillies and De Meillon, 1968; Mosha and Mutero, 1982).

Lake Baringo was not sampled consistently, but occasional spot checks over the study period indicated that A.gambiae was breeding along its edges all round the year.

Although a total of 17 mosquito species were collected and identified, only three of them are considered important with respect to the objectives of the study. These are the malaria vectors A.gambiae s.l., A.funestus and A.pharoensis. Incidentally these three were the first, second and fourth most abundant species in the area respectively, and the following discussion is restricted to them. C.quinquefasciatus which was the third most abundant species is mentioned occasionally, whenever there is a need to highlight the similarities or differences between Anophelines and Culicines and distant groups of mosquitoes.

Anopheles gambiae, A.funestus and Culex quinquefasciatus were found to breed all year round in parts of the Lobei Swamp. Larvae and gonoactive females were collected every month over the 2-year sampling period. The anophelines bred in the main body of the swamp which was open and sunlit at some points but was covered with both floating and emergent vegetations in most parts. The culicines bred mainly in marginal areas of the swamp that were being constantly grazed by domestic animals and whose water was usually polluted with animal dung and rotting vegetations. All the other species, including A.pharoensis were collected only at certain times of the year. Two species, namely A.gambiae and C.quinquefasciatus, were found breeding all round the year in the Perkerra irrigation scheme, the former in temporary pools resulting from intermittent

flooding of farmlands and the latter in older pools containing decaying vegetation. A.funestus was very scanty while A.pharoensis was completely absent in the irrigation scheme area.

These four species have been recorded as being widely distributed in other parts of Kenya. A.gambiae s.s. is reported as the predominant malaria vector in the more humid parts of the country, including the Lake Victoria basin, and coastal hinterlands while A.arabiensis is the predominant vector in the semi-arid and savanna areas such as the Tana River basin, Taveta Savanna and Mwea highland area (Symes 1928, 1940; Haddow, 1942; Mosha and Subra, 1982; Mutero, 1985). These authors also recorded A.funestus as being sympatric with the two gambiae species in most of the areas mentioned. A.pharoensis is recorded as being widely distributed in Trans-Nzoia and Kitale (Symes, 1931a,b), in Kisumu (Haddow, 1942) and in various parts of the coast (Van Someren et al., 1955).

C.quinquefasciatus has been reported as breeding in latrines, septic tanks peri-domestic containers and tree holes in Mombasa and other coastal areas (Van-Someren 1955) while Surtees (1970 c), Chandler and Highton (1975), and Chandler (1976) found it breeding in rice fields in Ahero and Kano plains. According to Subra (1980), latrines, soakage pits and septic tanks are the most widespread breeding sites in most countries, thus associating this species closely with urbanisation. From intermittent sampling in Marigat township during the present study the species was found breeding

prolifically in these types of sites and was the most abundant mosquito in the town. But in the locations where routine sampling was done no such 'urban' breeding sites were available and the species readily utilized swamp and irrigation water containing decaying organic matter.

3.4.2 Seasonal Abundance and Effect of Climatic Factors

According to Haddow (1942), in places where temperature is adequate for breeding throughout the year, A.gambiae, being almost entirely a puddle breeder, depends largely on local rainfalls, except in places where residual pools in empty river beds in the dry season provides suitable breeding grounds. In the present study, there was continuous breeding in both the Loboi swamp and the Perkerra irrigation scheme and it was only at Endau village that the breeding of this species depended entirely on the local rains. However, in the two locations at Loboi, Kapkuikui and Tingttiyon, as well as at Endau the population peak for A.gambiae was attained during the long rainy season, April to July. It was only at Perkerra irrigation scheme that the attainment of maximum population size did not occur during the long rains. There were drastic reductions in numbers in all the locations during the hot dry season (January-March)

In the Loboi locations and Endau, there was a steady increase in A. gambiae numbers with the onset of the rains in March which contnued until a maximum was reached in May at Kapkuikui, June at Tingttiyon and July at Endau. It would appear from this that the correlation between rainfall

and monthly catches would be well marked. However, when the coefficient of correlation r, was calculated it was non-significant in all three locations. This implies that although the seasonal abundance of A. gambiae in these places was connected with rainfall, the relationship was not a direct one. There are two possible explanations for this:

(i) Even though rainfall affects mosquito numbers by creating more breeding sites, temperature and relative humidity which regulate adult longevity may be more important in determinating the final population size. By influencing temperature and relative humidity, rainfall has an indirect effect on survival and hence on population size (Gillies and De Meillon, 1968; Bruce-Chwatt, 1985).

(ii) A. gambiae takes between 10 to 15 days to develop from egg to adult under optimum temperature conditions. There is therefore a time-lag between the emergence of new adults and the rainfall that created the breeding site.

The fluctuations in temperature and relative humidity were too little to have had any profound effect on population sizes (see Table 3), thereby making the first explanation most unlikely. In order to eliminate the effect of time lag, mosquito monthly collections should be plotted against the rainfall of the preceeding months. When this was done, the correlation was significant at Kapkaikui, Leboi ($r=0.583$. $F= 5.17$, $p<0.05$)

and at Endau ($r=0.704$, $F=7.97$, $p<0.01$), but not at Kinyattivon ($r=0.69$, $p>0.05$). In Kisumu, Kenya, Muddow (1942) found the relationship between rainfall and *A. gambiae* increase to be qualitative rather than quantitative. He found that the population in the first month of increase was proportional not to the amount of rain that had fallen but to the population in the preceeding month. This type of qualitative relationship was not observed in the present case.

Here breeding occurs mostly in a large body of water. Heavy rainfall may have the effect of inundating the breeding sites with flood water and washing away the larvae, thereby causing a decrease in numbers. In such situations peak populations are attained mainly towards the end of the rainy season (Service, 1963), or several months after the rains have stopped completely. Thus Dunkeen and Omer (1986) found an inverse relationship between the Nile water level and *A. arabiensis* production in nothern Sudan-the population density was lowest during the flood season (July - October) and increased as the river flow decreased between November and June. Snow *et al.*, (1987) found that the peak collection of *A. gambiae* females in a riverine area of the Gambia occurred 3 months after the onset of the heaviest rains.

At the Perkerra irrigation scheme, there was also a steady increase in *A. gambiae* numbers starting with the onset of the rains in March which continued until a population peak was reached in September, three months after the rains have stopped. There was no correlation between rainfall

and mosquito catches, even when this was plotted against previous months' rainfall. The population fluctuations seemed to depend more on irrigation practices adopted here than on rainfall patterns. The main channel leading from the dam was the only part of the irrigation system that carried water permanently. The secondary canals branching off from this and the feeder canals leading into the cultivated fields were filled with water only once a week. The basins in which crops were planted and the furrows separating them from one another were thus only flooded once a week to a depth of about 10 cm. The puddles formed as these and the canals dried up, provided suitable sites for A.gambiae breeding. During the dry season, however, many of these dried up too quickly to allow the completion of life cycle by the mosquitoes. In the rainy season these puddles increased in number and lasted longer. There were also additional sites created in car tracks, burrow pits etc, accounting for the rapid increase in numbers at this time.

There is also the practice by the irrigation board of diverting excess water from the main channel into disused canals anytime there was very heavy rainfall so as to prevent the former from overflowing its banks. The flow of water in these relief canals is slower than in the irrigation canals and therefore suitable for mosquito breeding. They became particularly ideal breeding sites for A.gambiae at the end of the rains when they begin to dry up, creating large stagnant pools in the process. These are mostly responsible for the peak populations between July and September.

Portions of these pools that become contaminated with decaying vegetation from harvested crops or weeded farms also favour the breeding of C.quinquefasciatus.

Rainfall has an inverse relationship with temperature, windspeed and a direct one with relative humidity, and is therefore cross-correlated to all three of them. Thus at Kapkuiltui where mosquito monthly catches has a significant positive correlation with rainfall, the monthly catches, has a significant negative correlation with temperature and windspeed and a significant positive correlation with relative humidity. The same type of situation was obtained at Endau, except that the relationship between catches and relative humidity was non-significant (see Table 4A). At Tingttiyon and Perkerra where there was no correlation between mosquito catches and rainfall, the relationship between catches and temperature, windspeed and relative humidity were also non-significant, except for relative humidity at Tingttiyon, (see Table 4A).

Table 4B illustrates the point that the stong linear correlation between mosquitc catches and some of the climatic factors did not in all cases imply a close association between them. Thus at Loboi only about 40%, on the average, of the A.gambiae catches was associated with changes in climatic factors, inspite of the strong linear relations. At Endau the association between changes in A.gambiae and changes in climatic factors was stronger, except for relative humidity. It ranged from 50% for rainfall to 65% for temperature. In all instances, however, care must be taken in interpreting

the results because as Snedecor and Cochran (1980) pointed out evidence of association between two variables is no proof that changes in the value of one was caused by the other.

Where temperature, relative humidity and windspeed are important in regulating mosquito numbers, they do so by regulating adult survival and longevity. Wind also affects activities such as feeding, flight range and oviposition (Gillies and De Meillon, 1968; Bruce-Chwatt, 1985). If this was the case in the present study, then both A.gambiae and A.funestus would have significant linear relations with these climatic factors, since they would affect the survival of the two species equally. But there was no significant correlation between A.funestus numbers and any one of these factors, indicating that they were not important in the regulation of mosquito numbers in this case.

The significant correlation observed between A.gambiae numbers and these three climatic factors at Kapkuikui and Endau must therefore be the result of their cross-correlation to rainfall. The non-correlation of A.gambiae relative abundance to rainfall at Perkerra was due to certain agricultural practices adopted on the irrigation scheme, as explained above, while the non-significant correlation of A.funestus numbers to rainfall at Loboi was probably due to some characteristic features of the breeding sites, as explained below.

Service (1965) found that at Kangimi, near Kaduna in northern Nigeria where small marshy patches of ground provided suitable breeding sites, A.funestus was almost as common as A.gambiae during the rainy season but in the early dry season it became the dominant species. On the other hand Symes (1932) in Kenya and Gibbins (1933) in Uganda found two seasonal peaks related to the two rainfall peaks in the year. In Kisumu, Kenya, Haddow (1942) found that there was a direct correlation between A.funestus numbers and the level of Lake Victoria. This was explained by the fact that a rise in lake level would extend the area of the lake margin covered with water and vegetation. The level of water in the Loboi swamp at different times of the year was not measured in the present study. However, it seems that during the heavy rains, between April and June, flood waters rushing into the swamp from the surrounding hills had an adverse effect on the development of larvae and negated any increases in numbers that would have resulted from increased water level. This was confirmed by the very low numbers of A.funestus adults collected at this time of the year. The optimal conditions for this species would expectedly be obtained a few months after the rains, when both the water level and the area covered by the swamp

was still high but the speed of flow of the water was minimal. This explains the increases between August and November. There was no significant correlation between A. funestus numbers and any other of the climatic factors measured at both Kapkuikui and Tingttiyon (see Table 4A).

Two important differences were observed between Kapkuikui and Tingttiyon (both in Loboi) with respect to Anopheles mosquito numbers and their relationship to climatic factors:-

(1) At Kapkuikui there was only one population peak for A. gambiae in May, but at Tingttiyon there were two peaks of approximately equal sizes in June and November.

(2) There was a significant correlation between A. gambiae catches and each of the climatic factors measured - rainfall, temperature, relative humidity and wind-speed-at Kapkuikui but not at Tingttiyon (except with relative humidity). That is, A. gambiae numbers were regulated by climatic factors, especially rainfall, at the former location but not the latter.

Kapkuikui is located directly beside the swamp and the mosquitoes collected from here, especially during the dry season, bred entirely in the swamp. During the rainy season, however, additional temporary sites were created. Tingttiyon on the other hand, is further away from the swamp, upto 2km from the near end of it.

Secondly there is an all season river, River Loruwai, which passes through Tingttiyon, forming a vegetation-covered permanent swamp in a forested area beside the village. Villagers also regularly diverted water from this river to irrigate crops and pastures, expecially during the dry season, creating ideal breeding sites in the process. It would seem that most of the mosquitoes collected from this village bred in these sites created by Loruwai river rather than in the Loboi swamp. The river has its source in the Mogotio highlands some 60 km away and so does not depend entirely on the local rainfalls around Loboi for fluctuations in its levels.

The upsurge in A. gambiae numbers in this location in November was probably due to additional breeding sites created by the river as a result of the short rains which had started in the highlands in October. The sudden sharp drop in A. funestus numbers in November and the equally steep rise in December can also be explained in terms of water levels and speed of flow in the river resulting from the short rains in the highlands. The short rains in Marigat division are usually too little and sometimes completely absent and so do not appreciably affect mosquito breeding. Thus the non-correlation of Anopheles mosquito numbers at Tingttinyon to local climatic factors was due to the fact that their breeding sites were created essentially by rainfalls in another part of the district with an entirely different set of climatic conditions.

A.pharoensis, the only other anopheline mosquito of medical importance collected during this study, was caught mostly during the later part of the long rainy season (May-July). For the rest of the year it was virtually absent.

C.quinquefasciatus was the most common culicine collected. In Marigat township it was the predominant mosquito species, in keeping with its description as an urban breeder (Service, 1965, Subra, 1980) But even in the Loboi swamp and Perkerra irrigation it was found throughout the year, (in low numbers relative to A.gambiae and A.funestus). The numbers were highest between February and April, dropping considerably during the heavy rains and recovering somewhat at the beginning of the dry season, October-December.

CHAPTER 4

MORTALITY AND SURVIVORSHIP OF MOSQUITOES

4.1 Introduction

Bates (1941) recogineased that if the developmental duration of the larval instars were known, then it would be possible to work out the relationship between the numbers of each instar collected and their survivorship. By dividing the numbers of each instar by the instar duration, he compared the survivorship of instars of A.maculipennis in different habitats. This idea has been greatly expanded and developed mostly by Service (1971), 1973, 1976) so that life-tables can be constructed for immature stages of A.gambiae and other mosquitoes.

There are two methods of estimating developmental rates and survivorship of immature mosquitoes in nature:-

(a) Horizontal life-table method which is best used if the population has discreet, non overlapping generations

(b) Vertical life-table method which is best applied to populations with completely overlapping generations.

Both the Loboi swamp and the Perkerra irrigation scheme near Marigat were found to support mosquito breeding all the year round. Gonoactive females and 1st-instar larvae were collected throughout the year, indicating overlapping

generations. The vertical life-table method was therefore used to estimate the survivorship of immature A.gambiae in these two habitats between June 1986 and May 1987.

According to Miller et al. (1973), adult survival rate is the most important factor determining the stability of a mosquito population and its total egg production and is of critical importance in determining the vector potential of the mosquitoes. In populations with stable age distribution, the parous rate is a useful parameter for estimating the survival rate of the whole population in the course of each gonotrophic cycle (Davidson, 1954; Gillies and Wilkes, 1965). The parous rate can be used to compare the age-composition of different populations of the same species or the same population under different conditions, provided the parous and nulliparous groups are adequately sampled. Parous rates were used in this study to compare the age composition and survival of A.gambiae in the two habitats at different times of the year

4.2 Vertical Estimates of Immature Survivorship for A.gambiae s.l

4.2.1 Materials and Method

Estimation of larval instar duration

The duration of the developmental period of the larval and pupal instars are needed in the construction of the survivorship curve of the pre-imagines. Therefore while the collection of the samples for the estimation of survivorship

was going on in June 1986, a separate experiment was conducted to determine the instar durations. A modified version of the method used by Mogi et at. (1984) was adopted.

Engorged A.gambiae females collected from houses using sucking tubes were kept in cages containing 2% sugar solution at room temperature (27 - 32°C) until they became gravid. Petridishes containing either tap water or water from the Loboi swamp were put in the cages to serve as oviposition vessels. The eggs thus laid were left to hatch in the same type of water in which they were laid. Twenty-five first instar larvae from each type were put in aluminium pans (20cm, in diameter, 5cm deep) in four replicates, each containing the same type of water in which the incoming larvae were hatched. Dried yeast powder was added twice daily to the pans containing tap water, while water in the other pans was replenished every two days with fresh water from the swamp. The number of larvae in each pan and their developmental stages were recorded daily until the completion of adult emergence.

Estimation of Stage-specific Survivorship and construction of Life-tables.

Three experiments were conducted. The first one was at Loboi in June 1986, during the rainy season. The second experiment was also at Loboi in February 1987, at the height of the dry season. The third experiment was at the Perkerra irrigation scheme in May 1987, at the height of

the rainy season. The experiment could not be repeated at Perkerra during the dry season because breeding sites of suitable size and duration could not be found at this time of the year. The pools and puddles created by the weekly flooding of the crops were too small in size and only a few of them lasted long enough to support breeding, thereby making them unsuitable for the sampling method used. In each case the method of Service (1973) was used. Two hundred dips were made daily from pre-determined portions of the breeding site for 10 consecutive days, using an aluminium dipper 15cm in diameter and 5cm deep. The larvae taken in the 200 dips were pooled and taken back to the laboratory live. In the laboratory some of the larvae were removed for rearing to adults in order to confirm larval indentifications and verify that all specimens were in fact A.gambiae. Twenty anopheline larvae were randomly removed for rearing from each day's collection, giving a total of 200 for each experiment. The following proportions, out of the numbers that emerged into adults, were A.gambiae: 112/150 = 75%; 90/115 = 78.3%; 115/155 = 74%, giving an average of 75.8%. The rest were then fixed in 70% alcohol, after which they were identified, counted and scored to instars.

4.2.2 Results

A basic assumption of this method is that the population should be stable throughout the period of sampling; that is, the number of eggs laid per day should balance off

the number of deaths in all stages. If this assumption holds, then the age-specific distribution curve simulates the time-specific survivorship curve (Service, 1973, 1977). Since the sampling from each habitat was done over a short period of time, it was reasonable to believe that this was the case in these experiments. To obtain a graph of the age distribution, the total number of each instar collected over the ten-day period was divided by the appropriate instar durations. This is to correct for any bias created by differences in stage durations. From the rearing experiments described above the instar durations for A.gambiae in Marigat were found to be: I = 1.5 days, II = 3 days, III = 2 days, IV, = 3 days and P = 2 days, giving a total developmental period of 11.5 days. These corrected values (number/instar duration) give the numbers of larvae and pupae at the temporal midpoint of each instar and were plotted against age in days of the larvae and pupae. The resulting histograms represented the stage-specific age distribution. A curve was then fitted through the midpoints of each histogram block (instar) to give the age-specific age distribution curve which simulates the time-specific survivorship curve (Figs 26 - 28). It was not possible to draw a smooth, continuous curve through the mid points of the histograms as Service (1973) and Lakhani and Service (1974) did. The procedure adopted by Reisen and Siddiqui (1979) was therefore used. Segmented curves with the points joined with the aid of a straight adge were drawn. From these curves the number of individuals

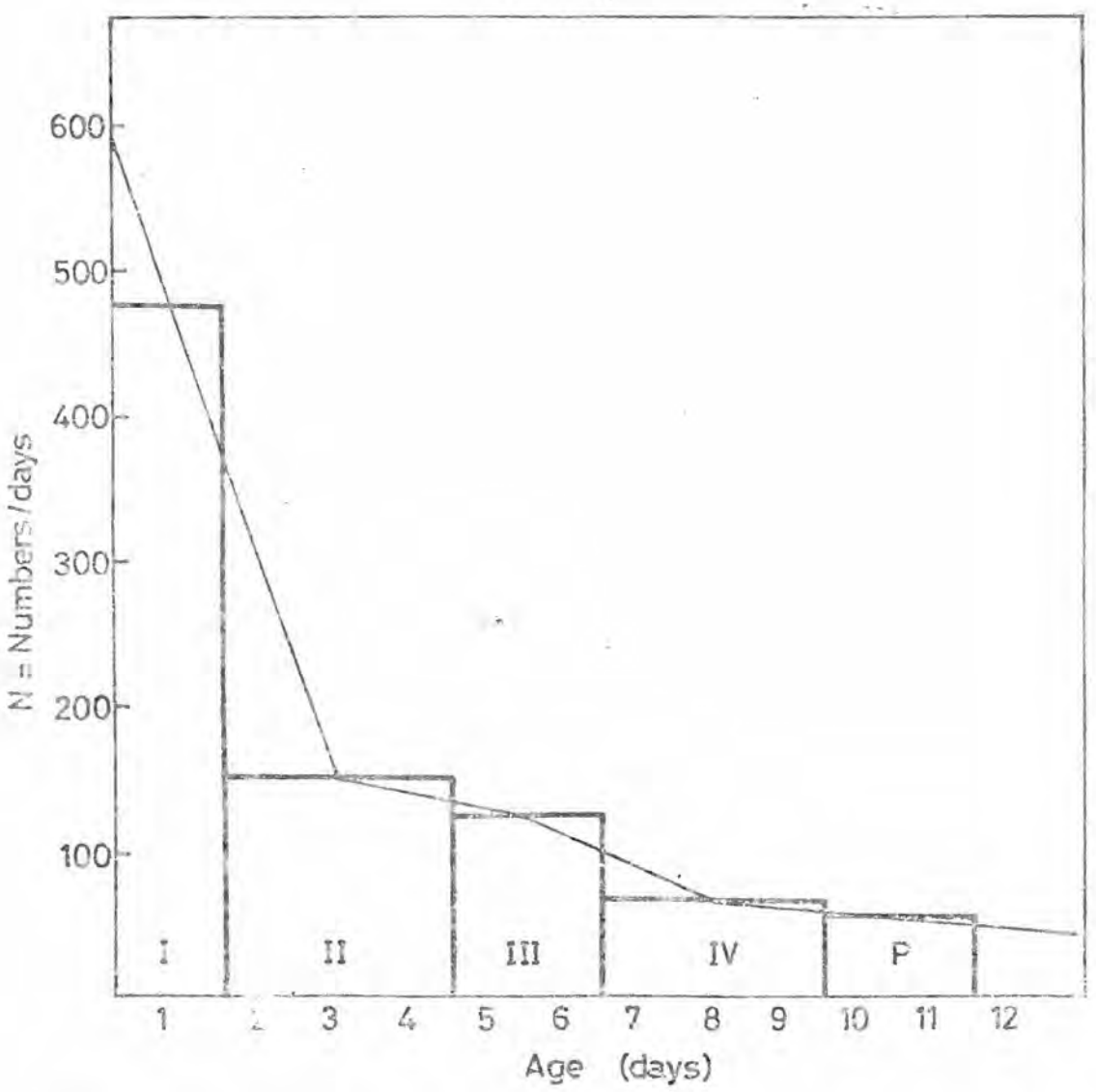


Figure 26: Graph showing the age structure of immature Anopheles gambiae S.l. at the Loboi swamp in June, 1986

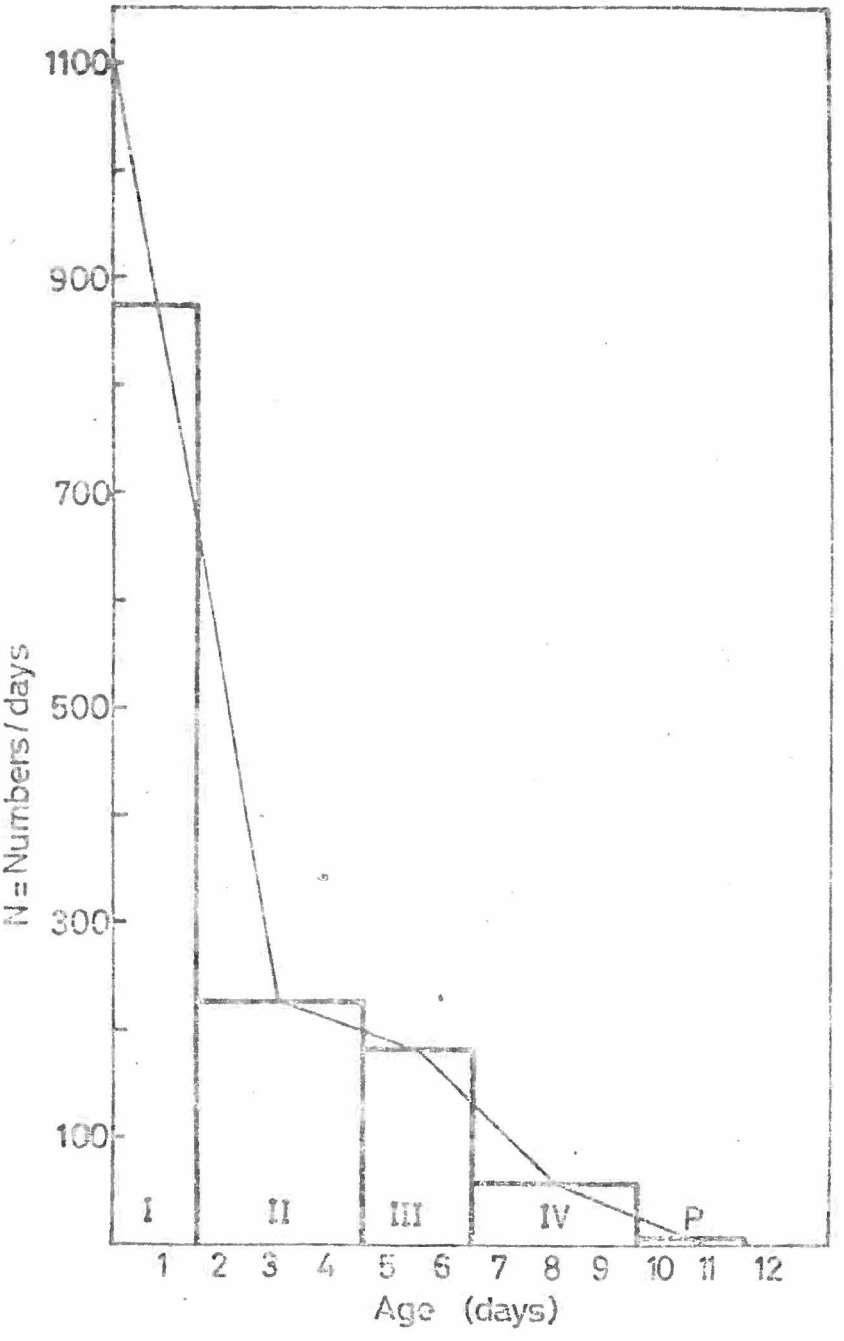


Figure 28: Graph showing the age structure of immature Anopheles gambiae S.l. at the Loloi Swamp in February, 1987

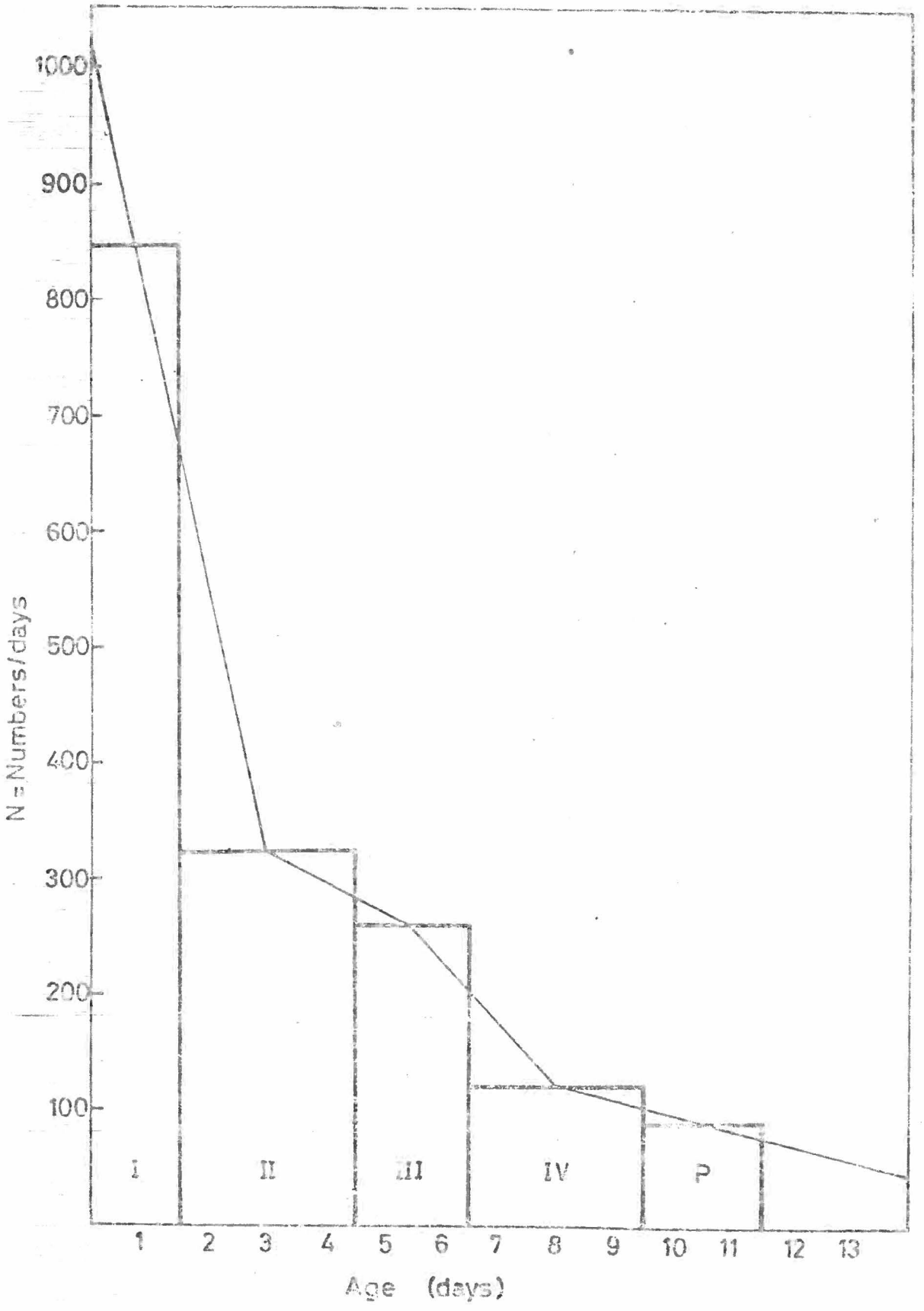


Figure 28: Graph showing the age structure of immature Anopheles gambiae S.l at the Perkerra irrigation scheme in May, 1987

Table 5: Numbers of Immature stages of A.gambiae s.l. collected each day in 200 dips from larval habitats, showing the coefficient of dispersion, C.D. = $S_2/\bar{X}$, for each instar.

collecting Habitat	No. of days	larval instars (I-IV) and Pupa Collected I	II	III	IV	P
EXP.1	1	23	18	10	8	3
	2	22	14	11	7	0
LOBOI	3	434	254	108	70	20
JUNE 1986	4	35	27	14	5	2
	5	43	19	19	7	0
	6	68	51	37	35	18
	7	21	18	20	12	1
	8	23	17	14	19	0
	9	19	17	10	22	7
	10	23	9	9	5	3
	TOTAL	711	451	248	192	54
Mean	$\bar{X}$	71.1	45.1	24.8	19.2	5.4
Variance	S^2	16486.1	5520.5	4931.29	407.07	56.04
C.D.	$S^2/\bar{X}$	231.87	122.41	37.55	21.20	10.38
EXP.2	1	62	26	16	8	2
	2	165	36	10	4	0
LOBOI	3	47	13	8	6	0
FEB.1987	4	48	15	6	3	0
	5	155	85	36	7	0
	6	155	68	29	7	1
	7	135	75	42	25	1
	8	143	93	67	29	0
	9	202	137	72	39	8
	10	200	130	81	43	0
	TOTAL	1312	678	367	173	12
Mean	$\bar{X}$	131.2	67.8	36.7	17.3	1.2
Variance	S^2	3441.73	2021.07	791.34	232.68	6.18
C.D.	$S^2/\bar{X}$	26.23	29.81	21.56	13.45	5.15

		Collecting No of larval instars (I-IV) AND Pupa collected				
Habitat	days	I	II	III	IV	P
EXPT.3	1	75	51	39	2	20
	2	204	165	73	50	36
PERKERRA	3	129	99	60	45	30
MAY 1987	4	81	66	38	21	15
	5	72	54	27	9	3
	6	99	84	52	45	3
	7	105	72	45	33	3
	8	90	72	54	45	15
	9	220	214	90	60	50
	10	120	84	40	32	6
	TOTAL	1271	961	518	366	181
Mean	$\bar{X}$	127.1	96.1	51.8	35.6	18.1
Variance	S^2	5002.77	2758.1	348.4	232.27	259.21
C.D.	$S^2/\bar{X}$	39.36	28.70	6.73	6.35	14.3

entering each stage was estimated by interpolation for the calculation of stage-specific survival rates and life-tables.

The total numbers of each instar obtained from 200 dips in each of the three experiments, together with their means, variances and coefficient of dispersion (Variance/Mean) are given in Table 5. In all the experiments, the coefficients of dispersion were higher than unity (that is, variances were higher than the means) indicating a highly aggfegated or clumped distribution. The 1st instar larvae were the most highly aggregated and aggregation progressively decreased as the larvae grew older (except between I and II in experiment 2). This is probably because the eggs were laid very close together by the females and also due to the relative inactivity of the 1st instar larvae. As the cohort mature, the larvae migrated further from the eclosion sites in search of food and more space. The cumulative effect of the various mortality factors which acted on the larvae as they grew must also contribute to the lower dispersion coefficients of the older instars.

The stage-specific survivorships are shown on Table 6. Survivorship from 1st instar to emergence was approximately equal (0.085) at Loboi and Perkerra during the rainy seasons (Expts. I and 3) but dropped drastically (0.000) at Loboi during the dry season (Expt. 2, Table 5). The largest proportion of larvae died in the 2nd and 4th instars in Experiments 1 and 3 while the lowest proportion

Table 6: Stage-specific survivorship of immature A.gambiae s.l. in the two larval habitats

Habitat	Instar	N	S_1	S	D_1	P_1	K_1
EXPT. 1	I	474	590	1.000	220	0.373	0.438
LOBOI	II	150	370	0.627	235	0.635	0.438
JUNE 1986	III	124	135	0.229	35	0.259	0.130
	IV	64	100	0.169	45	0.450	0.230
	P	54	55	0.093	5	0.091	0.041
	A		50	0.0847*	540		Σ = 1.042
EXPT. 2							
	I	875	1095	1.000	435	0.397	0.220
LOBOI	II	226	660	0.603	460	0.697	0.519
FEB. 1987	III	183	200	0.183	70	0.350	0.187
	IV	57	130	0.119	105	0.808	0.716
	P	6	25	0.023	25	1.000	-
	A		0	0.000*	1095		Σ =1.642
EXPT.3	I	847	995	1.000	320	0.322	0.169
PERKERRA	II	320	675	0.678	390	0.578	0.374
MAY 1987	III	260	285	0.286	85	0.298	0.154
	IV	120	200	0.201	94	0.475	0.280
	P	95	105	0.106	20	0.190	0.092
	A		85	0.0854	910		Σ =1.069

KEY:

N = Nc collected/stage duration = median age no = no at temporal mid point

S_1 = No entering each stage (estimated from the curves)

S = Survivorship from one stage to another,

* = 1st instar to adult survivorship, (A/I)

D_1 = No. dying during each stage, $S_1 - S_1 + 1$

P_1 = Proportion dying in each stage, D_1/S_1

K_1 = "Killing power" of each stage = $\log_{10} S_1 - \log_{10} S_1 + 1$

died in the pupal instars. But during the dry season (Loboi, February 1986, Expts 2) the highest proportion of larvae died in the pupal and 4th instar stages. The proportion dying daily in each instar was also consistently higher in this experiment than in the two others. In agreement with these, the sum of K (Killing power", Varley et al 1974) was highest in experiment 2.

Using the survivorship curves (Figs 26-28) the numbers of larvae surviving to each age in days were read off to give the Nx column in Table 7. These were then used to calculate a series of life-tables as shown (Table 7). Mean immature life expectancy for the first two days after hatching (X = 0,1,2) was higher at Perkerra (Expt. 3) than at Loboi (Expts. 1,2). From day 3 onwards the mean life expectancy was highest at Loboi (Expt. 1), followed by Perkerra (Expt. 3) and remained lowest in Expt. 2. Thus mean life expectancy was lower for all ages in the dry season (Expt. 2). An overll mortality of 91.9% and 100% was recorded at Loboi during the rains (June) and the dry season (February) respectively. The overall mortality at Perkerra during the rains (May) was 93.2%.

TABLE 7A: Life Tables for immature Anopheles gambiae s.l. at the Loboi swamp, June 1986 (Experiment 1)

X	NX	lx	dx	px	px	ex
0	595	1000	252	0.748	0.252	3.216
1	445	748	252	0.662	0.337	3.130
2	295	496	244	0.508	0.492	3.467
3	150	252	17	0.933	0.067	5.339
4	140	235	16	0.932	0.068	4.689
5	130	219	34	0.845	0.155	3.995
6	110	185	34	0.816	0.184	3.638
7	90	151	42	0.722	0.278	3.344
8	65	109	8	0.927	0.073	3.440
9	60	101	9	0.911	0.089	2.673
10	55	92	5	0.946	0.054	1.886
11	52	87	6	0.931	0.069	
12	48	81				

Table 7B: Life Tables for immature A.gambiae s.l. at the Loboi swamp, February 1987 (Experiment 2)

X	NX	lx	dx	px	qx	ex
0	1095	1000	260	0.740	0.260	2.610
1	810	740	274	0.630	0.370	2.351
2	510	466	260	0.462	0.583	2.440
3	225	206	17	0.917	0.083	3.890
4	207	189	15	0.921	0.079	3.193
5	190	174	32	0.816	0.184	2.425
6	155	142	46	0.676	0.324	1.859
7	105	96	46	0.521	0.479	1.510
8	55	50	18	0.640	0.360	1.440
9	35	32	17	0.469	0.531	0.969
10	16	15	15	0.000	1.000	
11	0	0				

Table 7C: Life Tables for immature A.gambiae s.l. at the Perkerra irrigation scheme, May 1987 (Experiment 3)

X	Nx	lx	dx	px	qx	ex
0	1025	1000	234	0.766	0.234	3.568
1	785	766	224	0.708	0.292	3.505
2	555	542	230	0.576	0.424	3.747
3	320	312	22	0.929	0.071	5.141
4	297	290	25	0.914	0.086	4.493
5	272	265	41	0.845	0.155	3.870
6	230	224	53	0.763	0.237	3.487
7	175	171	52	0.696	0.304	3.412
8	122	119	12	0.899	0.101	3.685
9	110	107	13	0.879	0.121	3.042
10	96	94	12	0.872	0.128	2.394
11	84	82	14	0.829	0.171	1.671
12	70	68	12	0.824	0.176	
13	57	57	56			

Overall mortalities = 91.9%, 100% and 93.2% for Expts. 1, 2, 3 respectively

Key:

X = age in days

Nx = No of larvae surviving to age x

lx = No per 1000 larvae surviving to age x

dx = Mortality between ages x and x + 1

px = probability that a larva of age x survives to age x + 1

qx = probability of a larva of age x dying before reaching age x + 1

ex = expectation of life for individuals of age x.

Predators

Many other arthropods were collected along with mosquito larvae during these and the other experiments involving dipping. These included several insects especially of the order Coleoptera, Odonata, Heteroptera and Ephemeroptera as well as Crustacea (Copepoda) and Arachnida (Araneae and Acari). Members of these groups are well known as predators of mosquito larvae and adults (Service, 1971, 1973; White and Rosen, 1973; Mogi et al., 1984, 1986). The most frequent found associated with mosquito larvae were identified as follows:

Table 8: Arthropods and other animals collected along with mosquito larvae

CLASS	ORDER	FAMILY	GENUS/SPECIES
Insecta	Coleoptera	Hydrophilidae	Globaria sp
"	"	"	Sternolophus sp
"	"	"	Helochares sp
"	"	Dytiscidae	
"	Heteroptera	Nepidae	Ranatra sp
	"	Belostomatidae	Sphaerodema sp
"	"	Notonectidae	
"	Odonata		
"	Anisoptera		
"	Zygoptera		
"	Ephemeroptera		

Crustacea	Copepoda	Cyclopoidae
Arachnida	Lycosida	Araneae
"		Acari
Amphibia		Hyperalius sp.

During the experiments to determine the vertical estimates of immature survivorship, the number of other arthropods in the daily 200 dips were recorded. It was therefore possible to calculate the total number of these and the mean number per dip at the end of the ten days of sampling. The values for Loboi (June 1986) and Perkerra (May 1987) are given below in Table 9.

It was not possible to quantify the amount of mortality due to predation or to evaluate the importance of any of the organisms listed above as predator due to the limited time available for this project. Different types of small fish were observed in the Loboi Swamp, but only one was collected twice in dips. This was identified as Aplocheilichthys antinorii. It is a cyprinidont annual fish sometimes called killifish. Its status as a predator on mosquito larvae could not be established.

Table 9: Total number and Mean number/dip of animals collected from Loboi Swamp and Perkerra Irrigation scheme.

CLASS	ORDER/SUB	FAMILY		LOBOI	PERKERRA
Insecta	Coleoptera	Hydrophilidae	(A)	1850 (0.925)	500 (0.25)
"	"	"	(L)	758 (0.4)	90 (0.05)
"	"	Dytiscidae	(A)	190 (0.10)	30 (0.02)
"	"	"	(L)	300 (0.15)	88 (0.04)
"	Odonata	Cordullidae	(N)	1500 (0.75)	-
"		Zygoptera	(N)	750 (0.37)	400 (0.2)
"		Anisoptera	(N)	800 (0.4)	-
	Heteroptera	Nepidae	(N)	1235 (0.62)	450 (0.23)
	"	Belostomatidae	(N)	850 (0.43)	350 (0.18)
		Notonectidae	(N)	250 (0.13)	-
	Ephemeroptera (N)			2100 (1.05)	-
Crustacea	Copepoda	Cyclopoidae	(A)	950 (0.46)	-
Arachnida		Araneae	(A)	250 (0.13)	155 (0.08)
Amphibia		Hyperalius sp	(T)	2090 (1.05)	1500 (0.75)

KEY: A = Adult, L = Larva, N = Nymph. T = Tadpole

4.2.3 Discussion

Survivorship of Immature Stages

Three basic assumptions are inherent in the method used in this study to estimate the mortalities and survivorship of immature A.gambiae in the two types of habitat investigated. These are (i) that the age structure of the pre-imagines in these habitats was stable (ii) that the various larval and pupa instars had the same dispersion patterns, and (iii) that the dipper used sampled all the immature stages with the same degree of efficiency.

Larvae of all stages and pupae, except on a few occasions during the dry season, were collected everyday during each of the experiments. This is an indication that the age structure was relatively stable, thus justifying the first assumption. The second assumption was tested by calculating the coefficient of dispersion, that is, variance/means for each immature stage from the data collected during each experiment. In all cases, the value was higher than unity, indicating a highly aggregated or clumped distribution. The younger stages were more clumped in their distribution than the older ones and this is atributable to oviposition habits of the females, in laying the aggs close together, the relative inactivity of the younger instars and the greater cumulative affects of mortality factor on older instars. With regard to the third assumption, Service (1973) noted that it was likely that different immature stages of A.gambiae exhibited different mathematical

forms of contagious distribution. If this was so, they would be sampled differentially by any one method. However several workers, including Service (1971, 1973, 1977), Lakhani and Service (1974), Reisen and Siddiqui (1979), Reisen et al. (1982) and Mogi et al. (1984 1986) considered the third assumption self-evident and obtained reasonable results.

To these three assumptions may be added the assumption in the precent study that instar durations derived from laboratory experiments alone were applicable to pre-imagines developing in natural habitats. The basis of this assumption was that no significant difference was found between the larvae reared in tap water on artificial diet and those reared in the swamp water both in terms of the total numbers that completed development and in terms of mean developmental time ($p > 0.05$ by X^2 in each case). The only other factor, apart from food and physico-chemical properties of the water, which could make a difference between larval development in the laboratory and the field was temperature. However, temperatures in Marigat area were consistently high and stable throughout the study period that any such difference must have been negligible.

The survivship from 1st instar to adult using the vertical stage-specific frequency distribution (Table 6) was the same at both Loboi and Perkerra during the rainy season (0.085), giving a mortality of 91.5%. The mortality for this season calculated from the age-specific life

tables (Table 7) was 91.9% and 93.2% for Loboi and Perkerra respectively. In February, at the peak of the dry season, the survivorship at the Loboi swamp dropped to zero with only a few pupae hatching from the 4th instar larvae and virtually none of these emerging into adult. The high mortality rates are consistent with results by other workers, for example, more than 95% mortality by Christie (1958) for A.gambiae in Tanzania; 99-100% by Service (1971, 1973) for A gambiae in ponds and ditches near Kisumu, Kenya; 98% by Mogi et al. (1984, 1986) for Anopheles species in rice fields in the Philippines and Thailand and 98 - 100% by Reisen and Siddiqui (1979) for C.tritaeniorhynchus in Pakistani ponds.

The highest mortality occurred in the 1st and 2nd instars. Thus 84%, 82% and 78% of the mortalities in experiments 1, 2, 3, respectively were in these two stages (Table 6, column D_I). The survivorship curve was accordingly a type IV in all cases, (Slobodkin 1962). Mean life expectancy, ex, during the period of highest mortality (age = 0,1,2, days) was highest at Perkerra (ex=3.6), followed by Loboi in June (ex=3.3) and least in Loboi in February (ex=2.5). Life expectancy generally increased for the older larvae that survived beyond this period (Figs 26 - 28, Table 7).

Mortality in the immature stages of mosquitoes can be caused by a number of factors, including adverse

climatic conditions, limited food supplies, predation, parasites and pathogens. Service (1973) found between 77 - 94% of 3rd and 4th instar larvae of A.gambiae in ditches and pools at Chiga near Kisumu, Kenya to be infected with Coelomomyces and attributed the high larval mortality to this fungus. No evidence of infection with Coelomomyces or any other pathogen was detected in the present study and predation appeared to be the most important factor responsible for the high mortality. The dominant groups of predators encountered included Hydrophilidae and Dytiscidae (Coleoptera) larvae and adults, Odonata nymphs, especially of the family Cordullidae and suborders Zygoptera and Anisoptera, Heteroptera nymphs of the family Nepidae and Belostomatidae, amphibian tadpoles including the predaceous Hyperolius species and spiders which were mostly surface predators. Service (1971, 1973), Reisen and Siddiqui (1979), Mogi et al. (1984, 1986) also found members of these groups as improtant predators of mosquito pre-imagines.

By using predator-free cages to breed mosquitoes in natural habitats and then comparing the adult emergence rates with those obtained from unprotected sites, Reisen and Siddiqui (1979) were able to make gross estimates of the effect of predation on the survival of C.tritaeniorhynchus in Pakistani ponds. They observed that the magnitude of predations mortality changed seasonally, being lowest in the monsoon and highest in the post-monsoon season. Using the same method, Mogi et al. (1984, 1986) found that preda-

tion by other insects was the most important mortality factor for mosquito immatures in both Phillipine and Thailand rice fields. They estimated that between 19 - 54% of immatures were lost to aquatic predators and another 1 - 10% to surface predators, (those which move on the surface and feed on emergent adults eg spiders). They could not, however, establish the sources of the non-predator related mortalities. The higher mortalities at Loboi in February (experiment 2) may be due, at least in part, to increased competition for food and space. At this time of the year a greater portion of the swamp has dried out and breeding is restricted to a much smaller area than in the rainy season. Predation would also be expected to be higher since the predators were also concentrated in the smaller breeding sites available.

4.3 Estimation of Adult Survivorship

4.3.1 Materials and Method

4.3.1.1 Dissection for simple age grading in females

The ovaries of unfed or freshly fed female mosquitoes were extracted and examined for the presence or absence of tracheolar skeins (tightly coiled terminals of tracheoles) by the method of Detinova (1962):- A freshly killed mosquito was placed on its side on a clean slide after the wings and legs were removed. A drop of distilled water was put

near the abdomen. One dissecting needle was inserted in the thorax while a second needle was used to make two small incisions between the sternites of segments 6 and 7. The ovaries were then extracted and immediately transferred to the centre of the drop of water and then left to dry out. In drying out air entered the tracheae, making the whole tracheal system including the smallest trachioles supplying the ovaries, to become clearly visible. The slide was examined under a x40 objective. The presence of skeins showed that the female was nulliparous, whereas the presence of a tracheal net without skeins showed that the female was parous.

4.3.1.2. Estimation of Parous Rates

Unfed and freshly fed female A.gambiae from fortnightly collections, using the pyrethrum spray method, were dissected for parity by the ovarian tracheation technique, as outlined above, between February and October 1987. If there were less than 50 females of the appropriate abdominal stages, the entire collection was dissected; from samples of 50 to 150, 50 were randomly selected and dissected; and from samples of 150 and over, 75 were selected and dissected. Estimates of the parous rates, based on the monthly totals, were calculated. However, daily survival rates were not calculated from these parous rates because two samples per month

were too few and estimates of daily survival rates based on them would contain a high degree of error. A separate experiment was therefore conducted for the estimation of daily survival rates.

4.3.1.3. Estimation of Daily Survival Rates

Daily collections of mosquitoes by the human bait method was carried out for 30 days at Loboi (from 8.5.87 to 6.6.87) and for 25 days at Perkerra (from 9.6.87 to 3.7.87). The collections were made between 7 p.m. and 1.00 a.m. each day as described in section 2.3.4. and the unfed and freshly fed A.gambiae were dissected for parity. At least 30 mosquitoes should be dissected daily for this experiment according to Birley and Rajagopalam (1981). This number could not be met on some occasions, but the actual numbers dissected were close to 30.

The parous rate formula (Davidson, 1954) provides a good estimate of the average survival rate per oviposition cycle only if the recruitment rate is reasonably constant. It is not valid under conditions where the recruitment rate is changing rapidly (Birley and Rajagopalan, 1981; Birley and Boorman, 1982). It was therefore necessary to first assess the validity of this method in estimating the survival rates of A.gambiae in the Marigat area by evaluating the constancy or otherwise of the recruitment

rate of this species at the time of the experiment. A graph of the number of mosquitoes per person per night was plotted for the total number dissected, number parous and number nulliparous, in order to show their patterns of fluctuation. If the fluctuations were great it meant that the recruitment rate was reasonably constant and the daily survival rate can be estimated from the parous rate with a high degree of accuracy (Birley and Rajagopalan, 1981). The cumulative totals of the numbers dissected daily ($\leq T$), and the numbers parous ($\leq M$) were calculated and ($\leq M/\leq T$), which represents the parous rate per oviposition cycle, was estimated. A graph of ($\leq M/\leq T$) x 100 was then plotted. The value of ($\leq M/\leq T$) varied very little throughout the experiment in both habitats but especially as from day 18 at Perkerra. This is a strong indication that the populations were stable and that the recruitment of nulliparous females was constant. The parous rate was therefore a good estimate of the survival rate.

The daily survival rate was then calculated from this mean parous rate using the parous rate formula of Davidson (1954):

$$p^n = M$$

where P is the probability of surviving through one day n is the length in days of the oviposition cycle M is the proportion parous in the population

4.3.2. Results

4.3.2.1. Estimation of Parous Rates

The results are shown on Tables 10 and 11 for perkerra respectively.

At Loboi there was a significant difference between the lowest parous rate of 43% in February and the highest rate of 81% in July (X^2 = 14.8, p<0.001). At Perkerra also the lowest rate of 40% in February was significantly different from the highest rate of 86% recorded in September (X^2 = 13.7, p<0.001). The mean parous rates for the two locations were 67% and 72% for Loboi and Perkerra respectively and there was a significant difference between them (X^2 = 6.7, p<0.010).

It is possible to divide the nine months of this experiment into four periods corresponding to different climatic conditions (see section 3.3.3.) thus: February-March, April-June, July-September, and October. The mean parous rates over the four periods in the two locations were as follows :

	Loboi	Perkerra
February-March	55.5	49.5
April-June	71.3	74
July-September	74.7	83.3
October	58	76

Table 10: Age Composition (Parous Rates) of Anopheles gambiae s.l. at Loboi, February to October, 1987.

MONTH	NO COLLECTED	NO DISSECTED	NO NULLIPAR	NO PAROUS	PAROUS RATE(%)
Feb	35	35	20	15	43
March	80	50	16	34	68
April	120	50	16	34	68
May	300	75	22	53	71
June	210	75	19	56	75
July	200	75	14	61	81
Aug	120	50	12	38	76
Sep	75	50	17	33	67
Oct	61	50	21	29	58
Mean					67

Table 11: Age Composition (Parous Rates) of A.gambia s.l at Perkerra, February to October, 1987.

MONTH	NO COLLECTED	NO DISSECTED	NO NULLIPAR	NO PAROUS	PAROUS RATE(%)
Feb	15	15	9	6	40
March	22	22	9	13	59
April	20	20	6	14	70
May	20	20	5	15	75
June	55	50	12	38	77
July	100	75	9	41	82
Aug	200	75	14	61	82
Sep	250	75	10	65	86
Oct	151	75	18	57	76
Mean					72

At both locations there were significantly more parous females during the rainy season, April-June, than during the hot dry period, February-March (X^2 = 4.6, $p<0.05$; x^2 = 5.6, $p<0.05$, for Loboi and Perkerra respectively). There were al also significantly more parous females during the cool dry period, July-September, than during the hot dry period, February-March (X^2 =7.7, $p< 0.01$; X^2= 17.3, $p<0.001$, for Loboi and Perkerra respectively). But there was no signifi - cant differnce in parous rates between the rainy season and the cool season ($p<0.05$).

There was no significant difference in parous rates between Loboi and Perkerra during corresponding periods of the year. However, from the summary given above it is obvious that the significant difference in the mean parous rates of the two locations over the nine month's period was mostly due to differences in age composition between July and October. When the period (July-October) was considered together, there was a significant difference between the parous rates of the two locations (X^2 = 6.3, $p<0.05$).

4.3.2.2. Estimation of Daily Survival Rates

The results of the daily dissections and the parous rates calculated from them are shown on Tables 12 and 13, and graphically as Figures 29 and 30. From these graphs

Table 12: Daily and Mean Parous Rates of A.gambiae s.l. at Koboi, in May,1967.

DAYS	NO. DISS (T)*	NULLIPAR (N)*	PAROUS (M)*	% PAROUS	ΣT	ΣM	MEAN RATE (ΣM/ΣT)%
1	35	14	21	60	35	21	60
2	34	16	18	53	69	39	57
3	30	16	14	47	99	53	54
4	36	17	19	53	135	72	53
5	26	9	17	65	161	89	55
6	24	12	12	50	185	101	55
7	28	16	12	43	213	113	53
8	23	11	12	52	236	125	53
9	28	14	14	50	264	139	53
10	31	18	13	42	295	152	52
11	30	15	15	50	325	167	51
12	33	10	23	70	358	190	53
13	31	10	21	68	389	211	54
14	21	5	16	76	410	227	55
15	20	6	14	70	430	241	56
16	29	10	19	66	459	260	57
17	26	5	21	81	485	281	58
18	23	3	20	87	508	301	59
19	24	12	12	50	532	313	59
20	27	14	13	48	559	326	58
21	30	9	21	70	589	347	59
22	23	5	18	78	612	365	60
23	25	5	20	80	637	385	60
24	35	8	27	77	672	412	61
25	40	10	30	75	712	442	62
26	30	5	25	83	742	467	63
27	28	5	23	82	770	490	64
28	38	7	31	82	803	521	64
29	34	4	30	88	842	551	65

* 2 day Running Means.

KEY: T = Total dissected; N = No. Nulliparous; M = No Parous; Σ = Cumulative total.

it can be seen that fluctuations in the nulliparous females were minimal, indicating a reasonably constant recruitment of newly emerged females into the populations. Therefore the parous rate can be regarded as a good estimate of the mean survival rate per oviposition cycle and the daily survival rate can be accurately estimated from it. The daily parous rates are shown in Figs. 31 and 32 while the mean parous rates per oviposition cycle are shown in Figs. 33 and 34. From these, the mean parous rates per cycle were read off as 65% for Loboi and 75% for Perkerra. Assuming a 2-day gonotrophic cycle, the mean daily survival rates were calculated as 0.81 and 0.87 for the two locations respectively. There was a highly significant difference between the two values ($X^2 = 17.3$, $p<0.001$).

4.3.3. Discussion

Survivorship of Adults

In the present study the parous rate was used to compare the age composition and survival of A.gambiae in the two habitats investigated at different times of the year. The results showed a seasonal variation in parous rates both within and between habitats. At Loboi the lowest rates were

Table 13: Daily and Mean Parous Rates of A.gambiae s.l. at Perkerra, in May,1987.

DAYS	NO. DISS (T)*	NULLIPAR (N)*	PAROUS (M)*	% PAROUS	T	M	MEAN RATE (M/ T)%
1	28	12	16	57	28	16	57
2	36	13	23	64	64	39	61
3	33	10	23	70	97	62	64
4	26	6	20	77	123	82	67
5	29	7	22	76	152	104	68
6	29	7	22	76	181	126	70
7	27	9	18	67	208	144	69
8	21	5	16	76	229	160	70
9	23	3	20	87	252	180	71
10	36	4	32	89	288	212	74
11	26	2	24	92	314	236	75
12	28	2	26	93	342	262	77
13	25	4	21	84	367	283	77
14	31	8	23	74	398	306	77
15	34	12	22	65	432	328	76
16	27	10	17	63	459	345	75
17	26	5	21	81	485	281	58
18	29	9	20	69	514	385	75
19	23	7	16	70	537	401	75
20	24	5	19	79	561	420	75
21	31	6	25	81	591	445	75
22	29	6	23	79	621	468	75
23	26	6	20	77	647	488	75
24	25	7	18	72	672	506	75

* 2 day Running Means.

KEY: T = Total dissected; N = No. Nulliparous; M = No Parous
= Cumulative total.

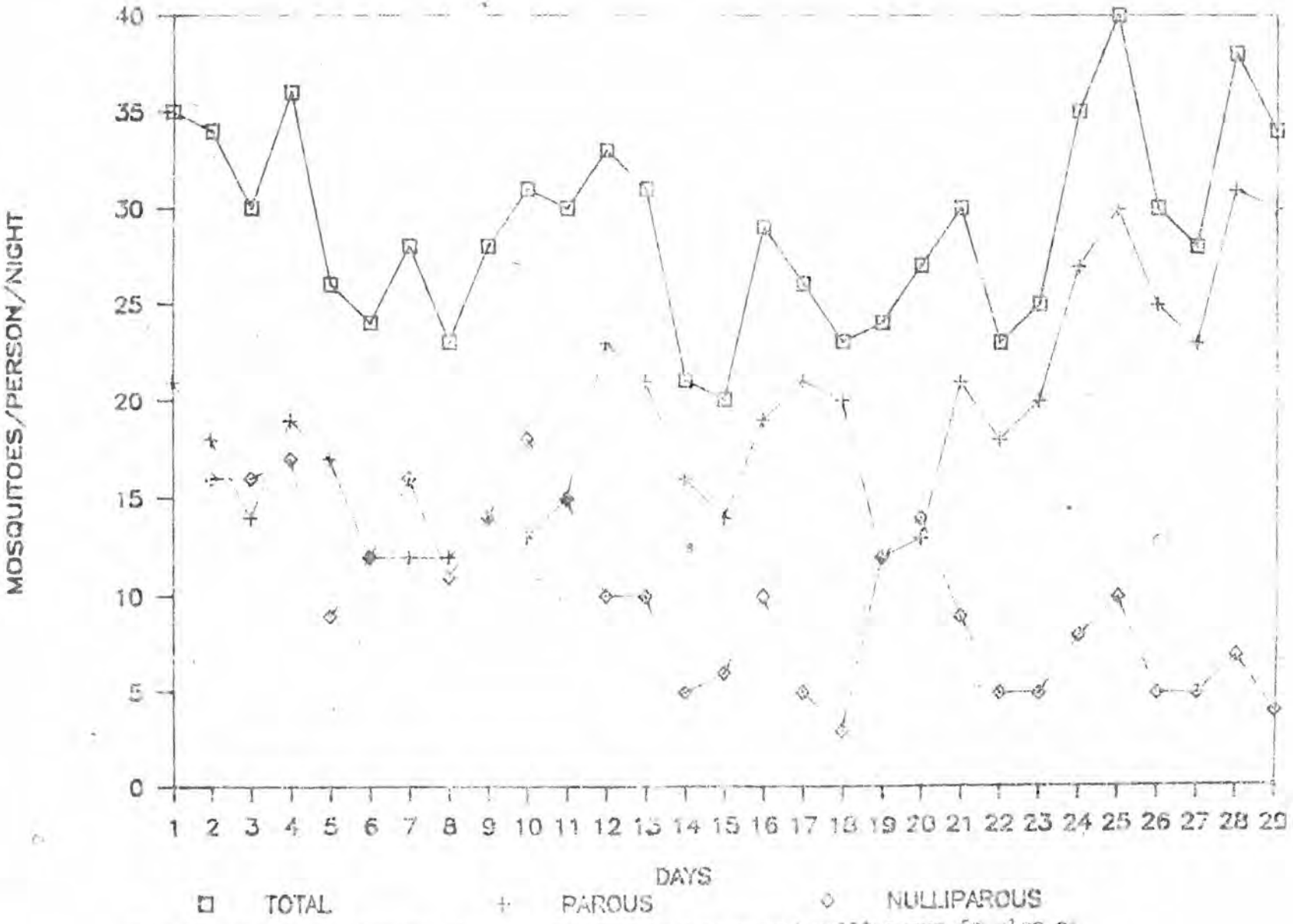


Figure 20: Graph showing the proportions of parous and nulliparous females of Anopheles gambiae S.l. in daily dissection of baited [illegible] May, 1987.

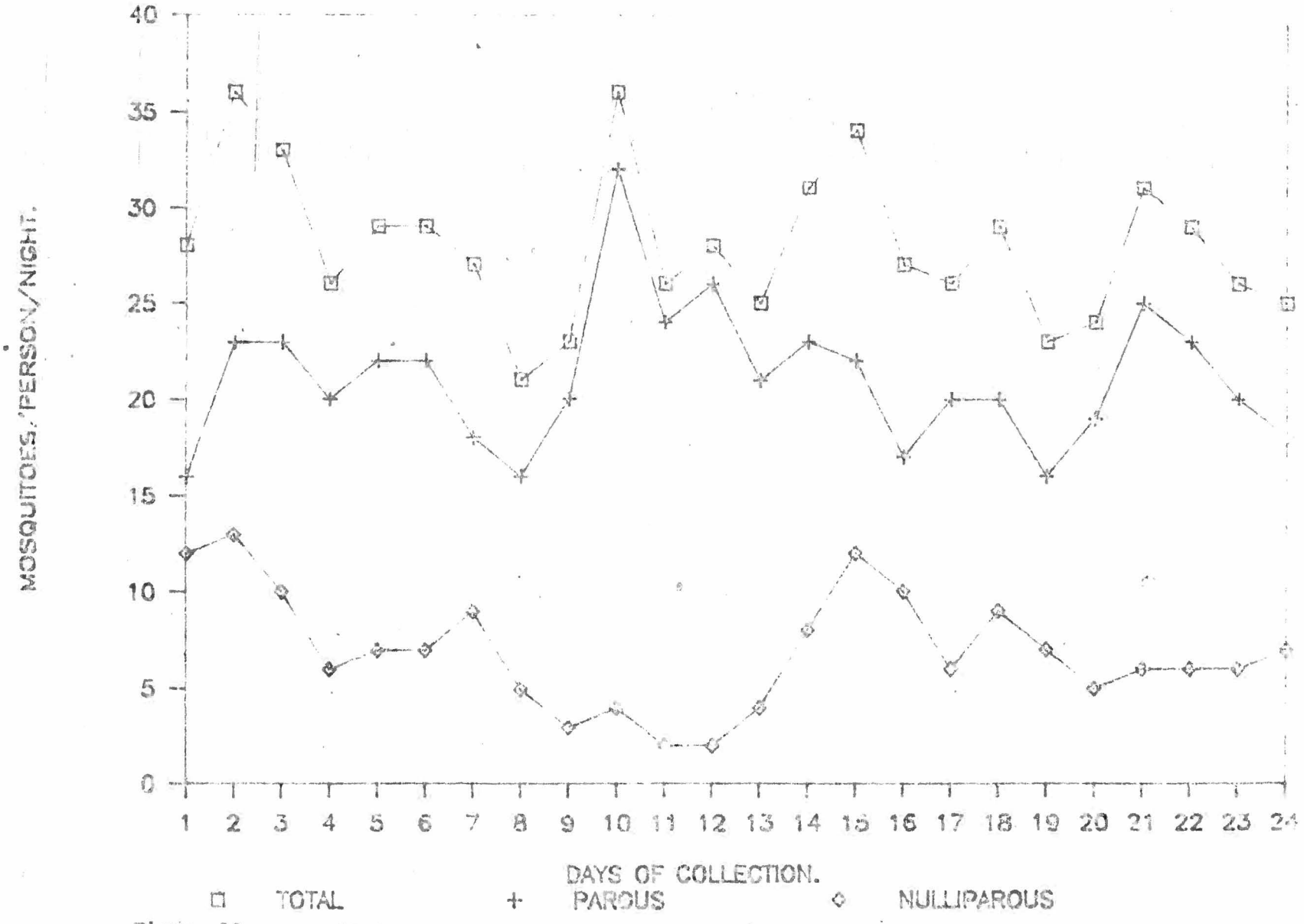


Figure 30: Graph showing the proportions of parous and nulliparous females of Anopheles gambiae s.l. in daily dissections at Korkoma in May, 1967

it can be seen that fluctuations in the nulliparous females were minimal, indicating a reasonably constant recruitment of newly emerged females into the populations. Therefore the parous rate can be regarded as a good estimate of the mean survival rate per oviposition cycle and the daily survival rate can be accurately estimated from it. The daily parous rates are shown in Figs. 31 and 32 while the mean parous rates per oviposition cycle are shown in Figs. 33 and 34. From these, the mean parous rates per cycle were read off as 65% for Loboi and 75% for Perkerra. Assuming a 2-day gonotrophic cycle, the mean daily survival rates were calculated as 0.81 and 0.87 for the two locations respectively. There was a highly significant difference between the two values (X^2= 17.3, $p<0.001$).

4.3.3. Discussion

Survivorship of Adults

In the present study the parous rate was used to compare the age composition and survival of A.gambiae in the two habitats investigated at different times of the year. The results showed a seasonal variation in parous rates both within and between habitats. At Loboi the lowest rates were

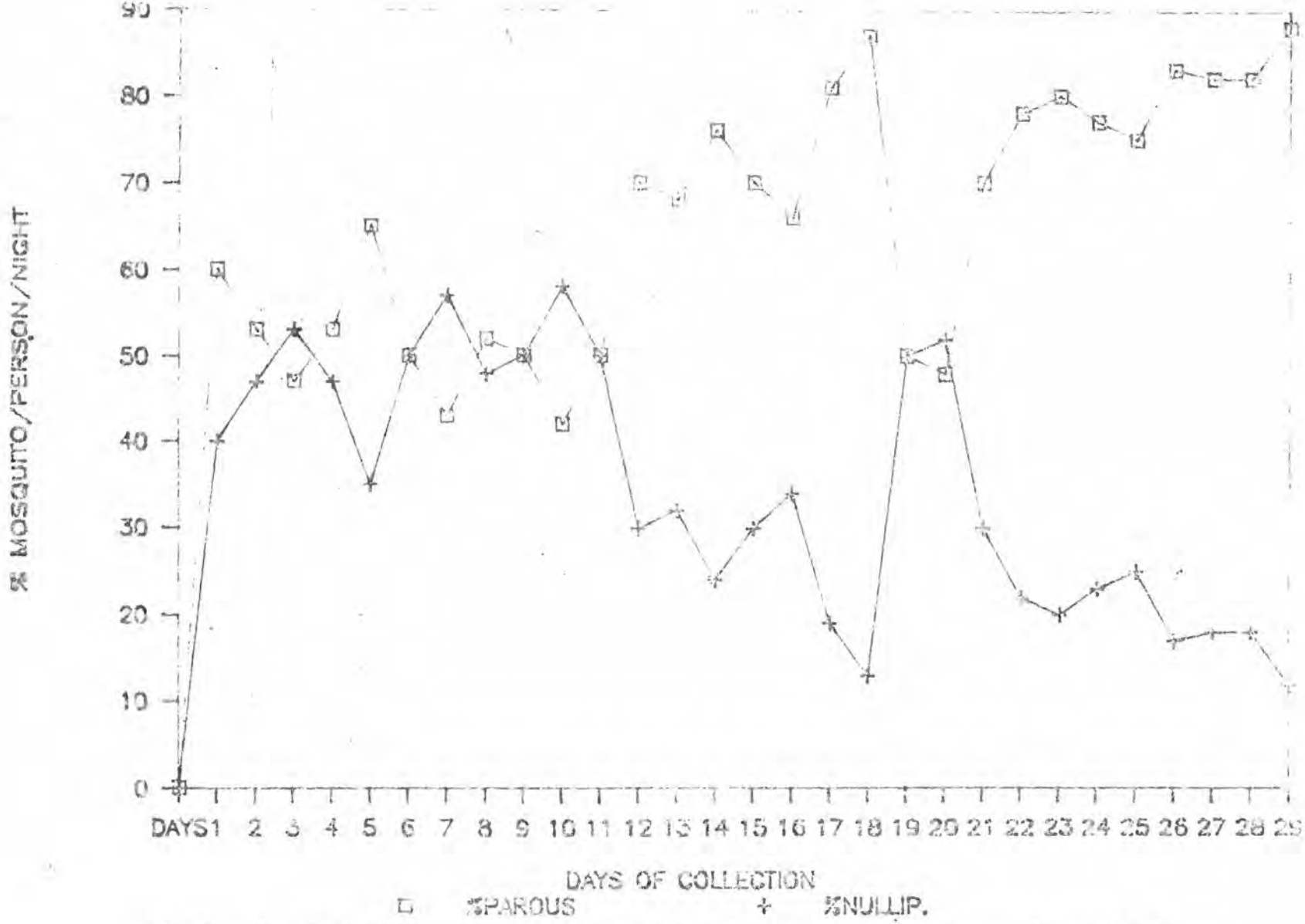


Figure 3a: Graph showing the daily percentage catch of anopheles funestus in a village in May, 1987

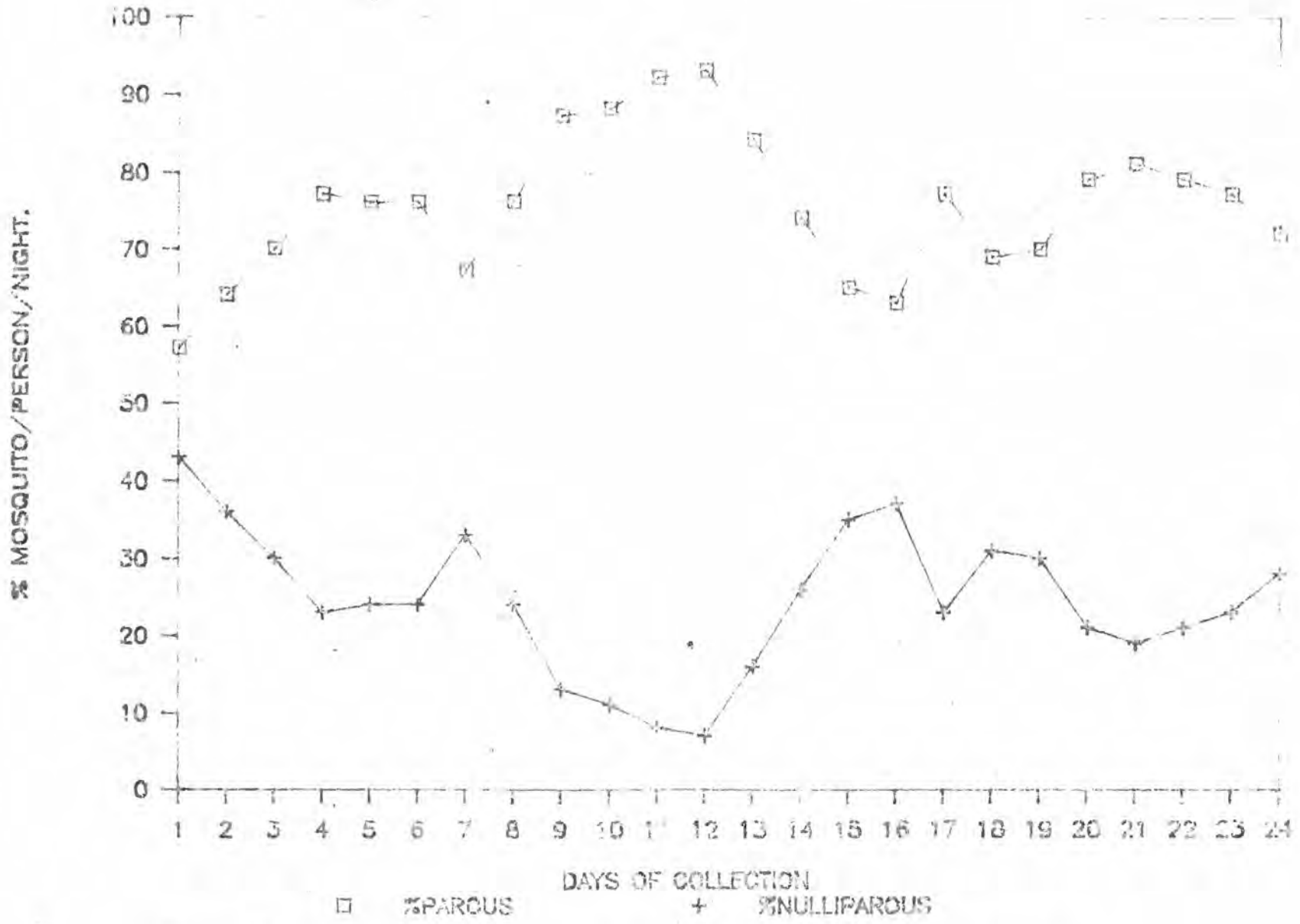


Figure 32: Graph showing the daily parous status of *Anopheles gambiae s.l.* at Prekorro in May, 1987

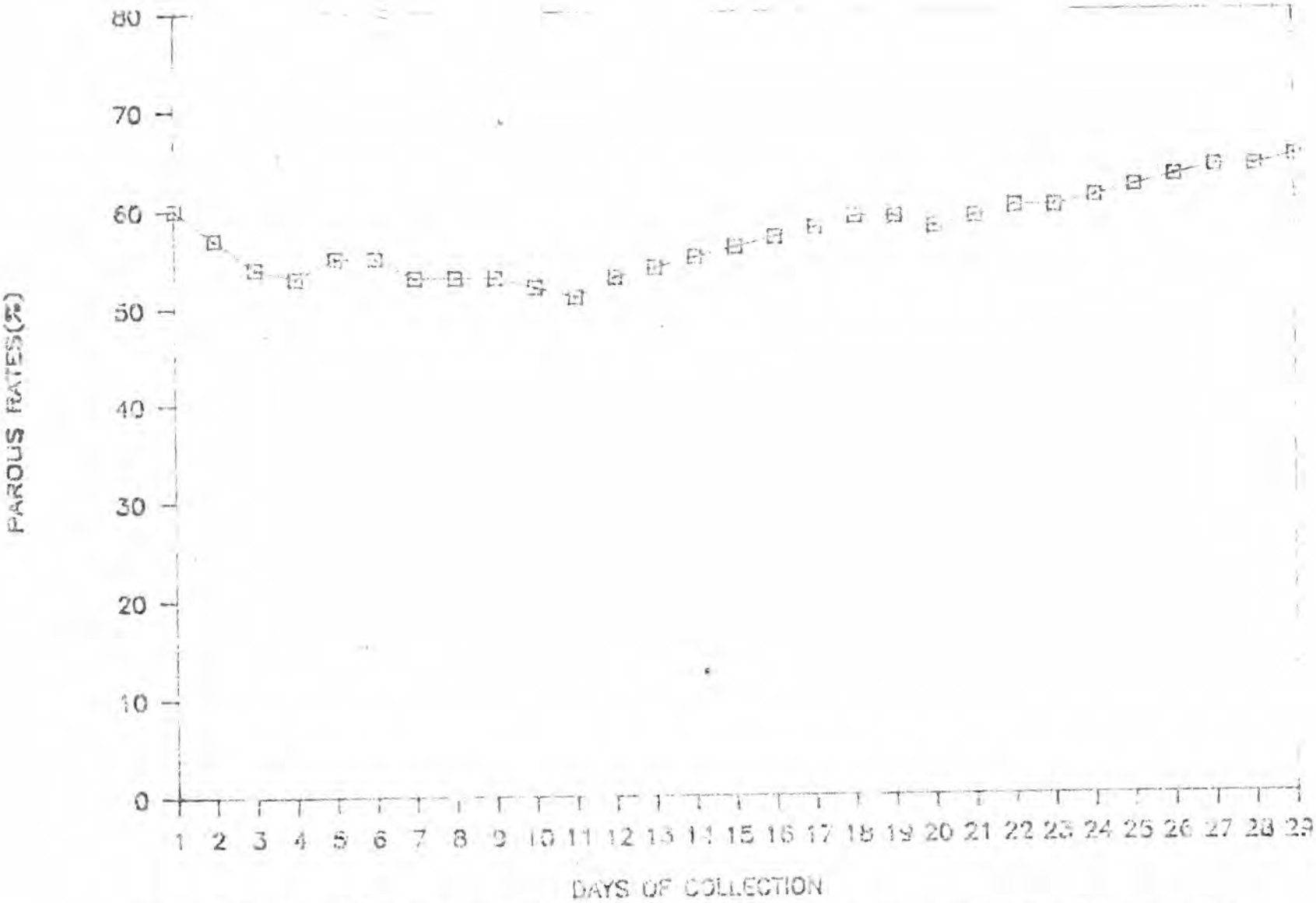


Figure 33: Graph of the mean parous rate per oviposition cycle of Anopheles gambiae S.l. at Loboi

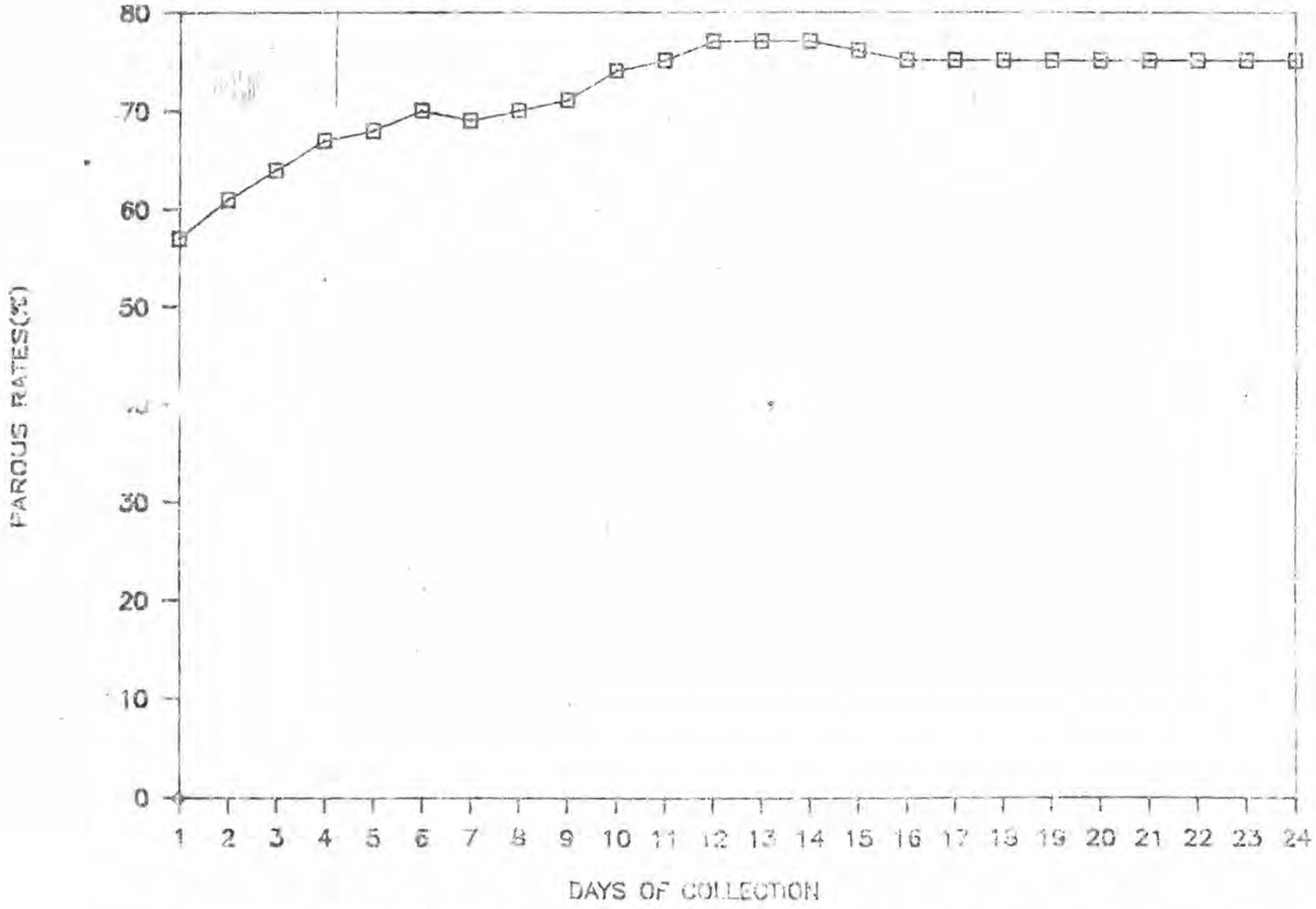


Figure 34: Graph of the mean parous rate per oviposition cycle of Anopheles gambiae s.l. at Pankouma.

recorded during the dry season and early rainy season, February March (Mean parous rate = 56%), while the highest rates were recorded during the cool dry period following the end of the rainy season, between July and September (Mean = 83%). In both places there was a significant difference between the lowest and highest parous rates recorded.

A 2-day gonotrophic cycle was assumed in calculating the daily survival rates for all months. This was based on the evidence of several workers who have studied the biology of A. gambiae in this part of Africa and found the gonotrophic cycle to be of 2-days duration under the prevailing temperatures ($23^{\circ}C$ and above all through the year) (Muirhead Thomson, 1951 a, b: Lewis, 1948; Macdonald, 1952; Davidson, 1954).

There was a significant difference between the mean parous rates at Perkerra and Loboi ($X^2=6.7$, $p<0.010$). This difference was due mostly to difference in the age composition in the two locations between August and October, since during the other periods the rates were not significantly different in the two locations. The reason for the greater parous rate at Perkerra between August and October is probably due to the greater shade and shelter provided by crops and trees which continue to flourish on the irrigated areas long after the rains have stopped. Irrigation is stopped or restricted to a small

area only between January and March when the water level in the Perkerra river becomes too low due, to the long dry season. Secondly, as has been pointed out earlier, A.gambiae attained its peak populations at Perkerra between August and October and at Loboi between May and July.

Thus the period of highest parous rates synchronized with the period of highest mosquito densities at Perkerra but not at Loboi. By August, the recruitment rate and already declined at Loboi but was still rising at Perkerra. The combination of factors which is optimal for mosquito breeding and survival was obtained at Loboi during the second half of the rainy season and at Perkerra about two to three months after the rains. Seasonal variations in the parous rates are indications of seasonal variations in survival rates. However, as stated already, survival rates could not be reliably estimated from the parous rates here because of the few samples from which they were calculated.

The daily survival rate of A.gambiae s.l. was significantly higher at Perkerra than at Loboi ($\chi^2 = 17.3$, $p<0.001$). Since the survival rates were measured only during the wet season, May/June, it could not be established whether or not it varied with the season. While some workers in the past found differences between the survival rates in the wet and dry seasons, others found no such differences. For example, Krafsur (1970) estimated the daily probability of survival

of Anopheles gambiae B and Anopheles funestus at Gambela, Ethoipia as p=0.89 in the wet season and p=0.79 in the dry season, the mean being p=0.85. The more advanced age-grading techniques of Gilles and Wilkes (1965) recorded p=0.85 for A.gambiae and p=0.83 for A. funestus in, Muhezi, Tanzania and observed no difference between the hot and the cool seasons. In Samoa, Samarawickrema et al. (1987), found parous rates of 37.9-49.7% and 36.6-59.5% for Anopheles samoanus and A polynesiensis respectively and noted that the rates were generally higher in the cool than in the warm season, suggesting higher daily survival during the cool period.

The parous rate formula (Davidson, 1954) assumes that mortality factors act equally on all adult mosquitoes irrespective of age, and several workers, including Gillies (1961); Miller et al. (1973); Spencer (1979); Charlwood and Wilkes (1979); Molineaus and Gramiccia (1980) and Russel(1986), among others made the same assumption in estimating the mortality and/or sporozoite rates of different species of mosquitoes. However, Gillies and Wilkes (1965) found that the mortality rates of A.gambiae in parts of Tanzania were constant between the first and seventh oviposition cycles and thereafter increased with age. Samarawickrema (1968) found that the mortality rates of M.uniformis in Colombo were reasonably constant during the first three gonotrophic cycles but increased with age thereafter. More recently, Clement and Patterson (1981) used a computer model (Gompertz model),

instead of the traditional exponential model to re-analyse many of the data available on parous rates, including some of those mentioned above, and showed conclusively that for most species the mortality rate does increase with age. In the present study, parous rates were estimated using ovarian tracheation only and no determination of physiological age by the number of ovariolar dilatation was done. The relationship of mortality with age was therefore not investigated. However, the parous and mean daily survival rates obtained were high enough, even during the dry season, to suggest that many females survive up to the age at which most malaria transmission occurs. This according to Gillies and Wilkes (1965) is between the 5th and 7th oviposition cycles.

CHAPTER 5

VECTOR BEHAVIOUR

5.1 Introduction

An understanding of the pattern of contact which a hae atophagous insect makes with its host is essential in determining the role of such an insect as a disease vector (W.H.O, 1972; Muirhead-Thomson, 1982). The extent and frequency of such a contact depends to a large extent on the feeding behaviour, the time and place of activity of vector, as well as on the presence and activity of the host at the same time and place.

In studying the behaviour of the three major Anopheles species encountered in the present project, the following three aspects of the feeding behaviour were therefore considered:

(a) biting activity, which refers to the frequency of landing and feeding on man,

(b) resting habits, which refers to the shelter preferences of these species when they are not feeding, and

(c) host preferences, which refers to their preference for man or any other animal in the presence of alternative hosts.

5.2 Materials and Method

5.2.1 Biting Activity

The collection of mosquitoes for the study of their biting activity was done by the human bait method as described in section 2.3.4. The term biting activity as used here refers to the actual landing and feeding on the host. The biting activity of A.gambiae s.l., A.funestus and A.pharoensis were studied over a period of four months, (April - July 1987). In each case the study covered the period between dusk and dawn, that is, between 1900 hrs and 0600 hrs.

5.2.2. Resting Habits

Mosquitoes collected from inside houses at Kapkuikui (Loboi) and Perkerra between January and December, 1986, using the early morning pyrethrum spray method as described in section 3.1.1 were analysed to study their daytime resting habits. The females were classified into the following 4 abdominal stage types:

i. Unfed females in which the abdomen was completely empty (without blood), narrow or collapsed.

ii. Freshly fed females in which at least the first six abdominal segments, viewed ventrally, were filled with red blood.

iii. Half gravid females in which the first three to five abdominal segements (viewed ventrally) were filled with dark coloured blood at various stages of digestion.

iv. Gravid females in which the blood was completely digested or remained as a narrow blackish line in the first abdominal segment and the abdomen was distended with eggs.

The late feds and subgravids which were separate stages in the W.H.O. (1975 a) classification have been included in the half gravid stage here. The unfed females were dissected and their ovaries examined to determine whether they were parous or multiparous.

Two types of outdoor sites were sampled for outdoor resting mosquitoes between January and December 1986. These were (1) Animal burrows in parts of the Perkerra irrigation scheme and near the Loboi swamp (2) vegetations around human habitation and animal enclosures at both sites. The animal burrows were sampled by the use of an updraft suction trap while the vegetations were sampled by the use of sucking tubes (constant time search, as described in sections 2.3.2 and 2.3.3. respectively). However, the number of mosquitoes obtained by the second method at Perkerra, mostly culicines were so few that they were excluded in the results presented below.

5.2.3 Host Preferences

Collection of Blood Smears for Host Preference Studies

Blood smears were taken from fed mosquitoes between June and October 1986, corresponding to the period of highest mosquito density. Collection of mosquitoes was done inside houses, from animal shelters and vegetation around houses and animal enclosures (as detailed in Section 2.1).

The mosquitoes were first identified, after which the wings and legs were removed. An individual was then placed on a filter paper, 10 cm in diameter, at a distance of about 1 cm from the edge. The abdomen was then squashed with a pin. Each filter paper contained eight blood smears, each of which was given a number corresponding to a similar one on the test request form. The filter paper itself was identified with an alphabet. The smears were left to dry properly after which they were packed in a plastic bag, with the filter papers separated from one another by non-absorbent white paper. The details required on the test request form included the sex, species, place and date of collection of each mosquito. The samples were sent to the Imperial College of Science and Technology, London where they were identified by the precipitin test technique.

5.3 Results

5.3.1. Biting Activity

The results are summarised in Tables 14 A and B

and Fig. 36. The figures given on the tables are the means for each period over the four months.

In A.gambiae activity both indoors and outdoors was lowest during the first two hours of the night (1900-2100 hrs). It increased rapidly over the next four hours, reaching a peak between 2300 hours and 0100 hours. Thereafter there was a gradual but steady decline until 0600 hrs. Approximately 58% of the total biting activity took place between 2300 hours and 0300 hours whereas only about 27% of the activity occurred during the first four hours, 1900 - 2300 hours and only about 17% occurred within the last three hours of the night, that is 0300 - 0600 hours (Fig. 35 (a)).

In A.funestus, activity indoor and outdoor was also lowest during the first two hours of the night. There was a steady increase in activity as the night progressed. The peak of biting activity was attained between 0100 hours and 0300 hours - two hours later than in A.gambiae. Approximately 25% of the biting activity occurred during the first four hours of the night, between 1900 - 2300 hours; 39% during the second four hours, 2300 - 0300 hours, and 32% during the last three hours of the night, 0300 - 0600 hours. thus there was a more even distribution of activity throughout the night, especially as from about 2300 hours till dawn in A.funestus than in A.gambiae (Fig. 35 (B)).

Table 14A: Biting Activity of Anopheles Mosquitoes Indoors at Loboi 1987

SPECIES / TIME	A.gambiae NO.	%	A.funestus NO.	%	A.pharoensis NO.	%
1900-2100 HRS	37	9.3	18	10.5	54	35.5
2100-2300 HRS	70	17.5	25	14.5	70	46.1
2300-0100 HRS	130	32.5	42	24.4	23	15.1
0100-0300 HRS	97	24.3	50	29.1	5	3.3
0300-0600 HRS	66	16.5	37	21.5	0	0.0
	400		172		152	

Table 14B: Biting Acivity of Anopheles Mosquitoes Outdoors at Loboi, 1987

SPECIES / TIME	A.gambiae NO	%	A.funestus NO	%	A.pharoensis NO	%
1900-2100 HRS	12	8.8	6	11.5	67	33.7
2100-2300 HRS	15	11.0	6	11.5	82	41.2
2300-0100 HRS	51	37.5	10	19.2	35	17.6
0100-0300 HRS	36	26.5	16	30.8	10	5.0
0300-0600 HRS	22	16.2	14	26.9	5	2.5
	136		52		199	

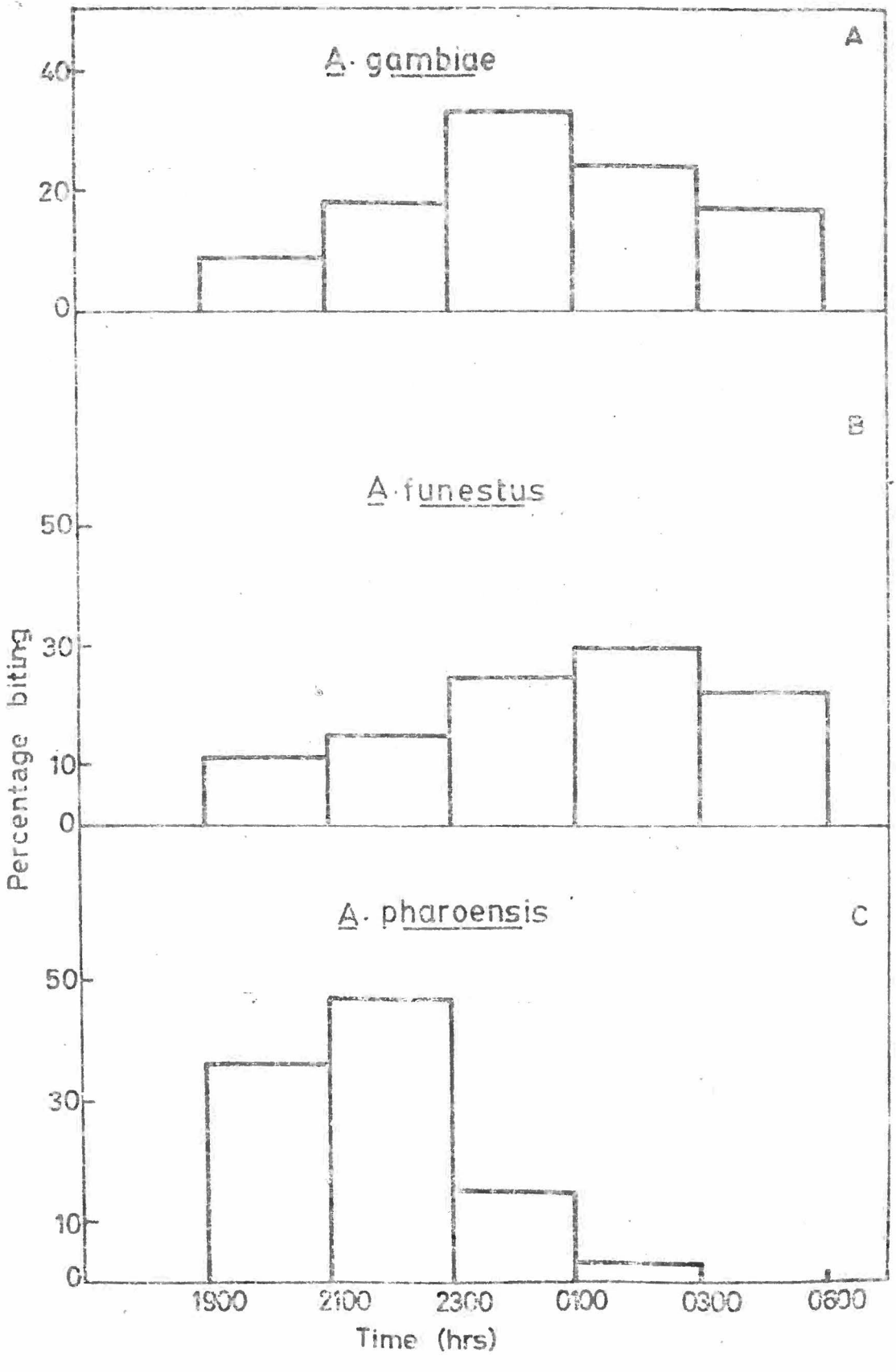


Figure 35: Graphs showing the biting activity of Anopheles mosquitoes

The biting activity of A.pharoensis was distinctly different from those of A.gambiae and A.funestus. Activity of A.pharoensis was very high soon after dusk; 36% of activity was recorded within the first two hours of the night (1900 - 2100 hours). Activity was slightly higher outdoors than indoors throughout the night. Peak biting occurred between 2100 and 2300 hours (46%) and thereafter biting declined sharply to about 15% (2300 - 0100 hours) and only 3.3% (0100 - 0300 hours). There was no biting activity after 0300 hours indoors but biting continued on a low scale outdoors until dawn. In this species, up to 82% of biting occurred during the first four hours of the night (1900 - 2300 hours) and there was virtually no activity during the second half of the night from 0100 hours till dawn (Fig. 35 (C)).

5.3.2 Resting Habits

The composition of the indoor resting mosquitoes according to their abdominal stages is given on Table 15 A and B below.

Table 15A Composition of indoor resting mosquitoes at Loboi according to their abdominal stages .

SPECIES / SEX/ABD STATE	A.gambiae NO	A.gambiae %*	A.funestus NO	A.funestus %*	A.pharoensis NO	A.pharoensis %*	Culicini NO	Culicini %*
Male	218	14.9	240	16.3	6	9.5	143	23.8
Female	1248	85.1	1235	83.1	57	90.5	457	76.2
UF	112	9.0	176	14.3	0	0.0	138	302
FF	631	50.1	484	39.2	47	82.5	97	21.2
HG	294	23.6	275	22.3	8	14.0	107	23.4
G	211	16.9	299	24.2	2	3.5	115	25.2
TOTAL	1466		1475		63		600	
%		40.7		40.9		1.8		16.6

Table 15B: Composition of indoor resting mosquitoes at Perkerra according to their abdominal stages .

SPECIES / SEX/ABD STATE	A.gambiae NO	A.gambiae %*	A.funestus NO	A.funestus %*	Culicini NO	Culicini %*
Male	74	8.8	5	17.9	21	32.8
Female	711	91.2	23	81.1	43	67.2
UF	54	7.0	1	4.3	12	27.7
FF	413	53.6	7	[illegible].4	10	23.3
HG	183	23.7	7	30.4	10	23.3
G	121	15.7	8	34.8	11	25.5
TOTAL	845		28		64	
%		90.7		3.0		6.8

KEY: UF = Unfed; FF = Freshly fed; HG = Half gravid; G = Gravid

* First two figures under the percentage column refer to percentage of total (male + female) others to females alone.

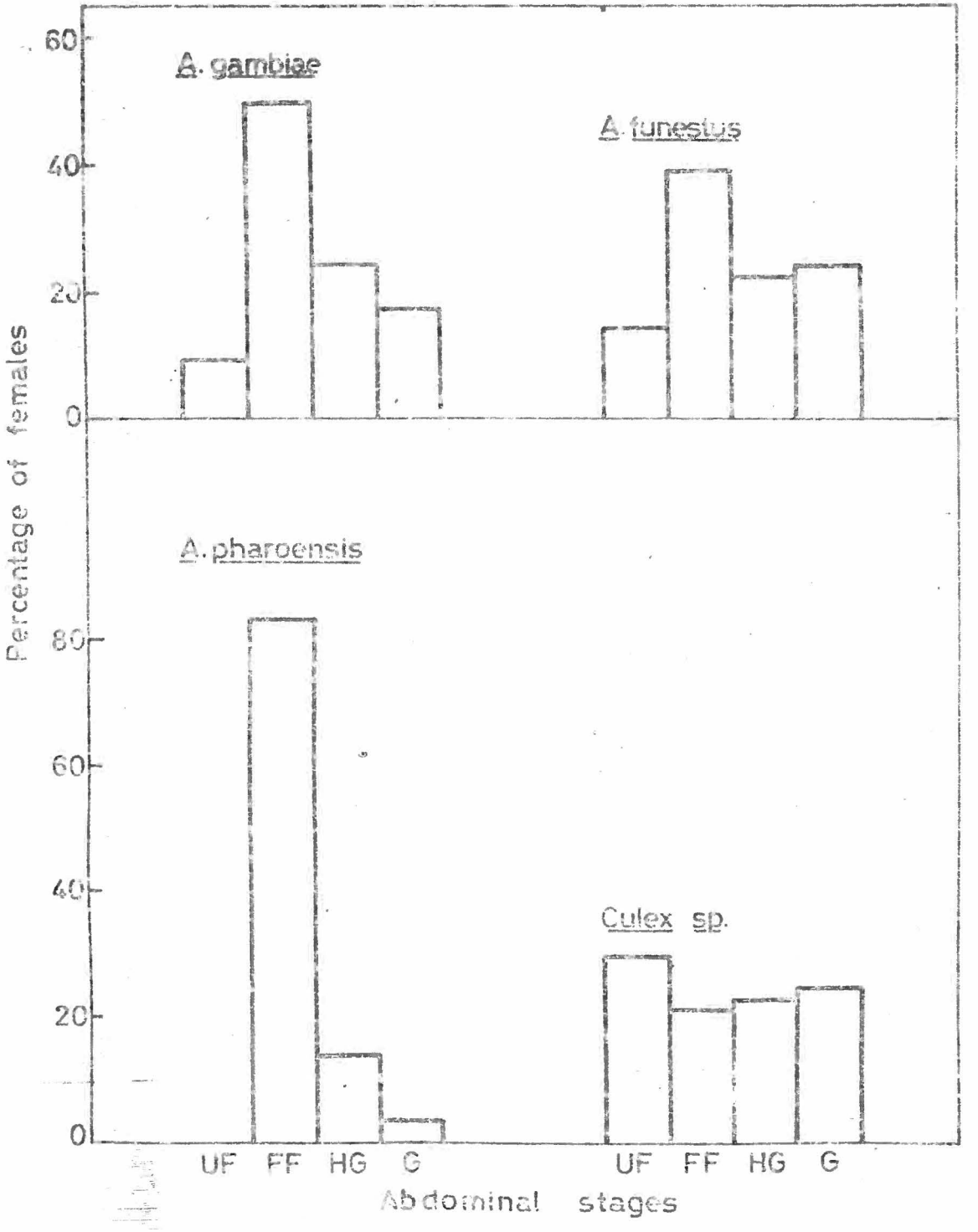


Figure 36: Percentage composition according to abdominal stages of female mosquitoes collected from inside houses by the pyrethrum spray method at Loboi.

A total of 1466 A.gambiae were collecte at Kapkuikui, Loboi. Two hundred and eighteen (15%) were males while the rest were females. There were 112 unfed females accounting for about 9% of the females colledted. Ovarian dissections showed that 95 of these (85%) were newly emerged nulliparous females. Approximately 50% of the indoor resting females were freshly fed while the half gravid and gravid females made up 24% and 17% of the females respectively.

The distribution of indoor resting A.funestus was similar to that of A.gambiae in most respects. A total of 1464 were collected, of which 240 (16%) were males and the remaining 1235 (84%) were females. One hundred and seventy-six (14.3%) were unfed. Ovarian dissection showed that about 90% of these (157) were nulliparous. Freshly fed females made up 39.2% of the females while the half gravids and gravids accounted for 22.3% and 24.2% respectively.

Only 63 A.pharoensis were collected indoors at Kapkuikui, Loboi. None was collected at Perkerra (Tables 15 A and B). Males were 9.5% of the total collection, while females accounted for 90.5%. Freshly fed females were 83% of the total females; half gravids and gravids made up 14% and 3.5% respectively. No unfed females were caught.

There were a number of striking differences between the composition of the indoor resting A.gambiae and A.funestus on the one hand and the indoor resting A.pharoensis on the other. The most obvious of these include:

(a) the complete absence of unfed females in the A.pharoensis collection (b) the very high percentage of freshly fed females in A.pharoensis (82.5%) relative to A.gambiae (50.1%) and A.funestus (39.2%). (c) the very low percentage of gravid females in pharoensis (3.5%) relative to A.gambiae (16.9%) and funestus (24.2%) (d) the relatively small percentage of males in A.pharoensis (9.5%) compared to A.gambiae (14.9%) and A.funestus (15.7%). These differences are discussed in detail in section 5.4.

The composition of the culicine mosquitoes collected indoors are included in Table 15 for purposes of comparison. The distribution according to abdominal stages were similar in many respects to those of A.gambiae and A.funestus except that: (a) the percentage of males was higher in the culicines than in the anophelines; (b) there was also a higher percentage of unfed culicines than anophelines; (c) the differences among numbers of the three categories (freshly fed, half gravid and gravid) were very small in the culicines compared to the anophelines. As stated in section 4.1 C. quinquefasciatus and C. zombiensis made up the bulk of the culicines collected indoors.

The main difference between Loboi and Perkerra with respect to indoor resting mosquitoes is that there were more mosquitoes (both in species, diversity and abundance.) at Loboi than at Perkerra. Thus, only 28 specimens of A.funestus were collected over the one year period (Jan-Dec. 1986) at Perkerra as against 1464 at Loboi and only 845 and 64 A.gambiae and culicines respectively were collected as against 1466 and 600 respectively at Loboi. A.pharoensis was not collected at all at Perkerra. With respect to composition of indoor resting mosquitoes, there was no significant difference between the two locations, on the basis of abdominal stages.

The composition of the mosquitoes collected from animal burrows in the two locations are shown on Table 16 A and B.

TABLE 16A: Composition of mosquitoes collected from animal burrows at Loboi according to their abdominal stages

SPECIES	A.gambiae		A.funestus		Culicini	
SEX/ABD STAGE	NO	%*	NO	%*	NO	%*
MALE	50	21.7	40	43.5	228	40.7
FEMALE	181	78.3	52	56.5	332	59.3
UF	59	32.6	16	30.8	231	69.5
FF	11	6.1	6	11.5	17	5.2
HG	44	24.3	10	19.2	39	11.7
G	67	37.0	20	38.5	45	13.6
TOTAL	231		92		560	
%		26.2		10.4		63.4

Table 16B: Composition of mosquitoes from animal burrows at Perkerra according to their abdominal stages.

SPECIES	A gambiae		A.funestus		Culicini	
SEX/ABD STAGE	NO	%*	NO	%*	NO	%*
MALE	14	19.2	12	44.4	121	44.3
FEMALE	59	80.8	15	55.6	152	55.7
UF	31	52.5	4	26.7	110	72.4
FF	6	10.2	2	13.3	6	3.9
HG	9	15.3	3	20.0	14	9.2
G	13	22.0	6	40.0	22	14.5
TOTAL	73		27		273	
%		19.6		7.2		73.2

KEY: UF = Unfed, FF = Freshly fed, HG = Half Gravid, G = Gravid

* First two figures under the percentage column refer to percentage of total (male + female), others refer to percentage of female alone.

The results are presented graphically in Fig. 37 A and B for A.gambiae and Culicini at Perkerra only. A total of 231 A.gambiae were collected from animal burrows around Loboi. Fifty (21.7%) were males while 181 (78.3%) were females. The bulk of the females (32.6%) consisted of unfed individuals; 85% were nullipars. Only 6.1% of the catch were freshly fed, while 24% and 37% were half gravid and gravid females respectively.

Of the 92 A.funestus collected from animal burrows at Loboi, 40 (43.5%) were males , and 52 (56.5%) were females. Unfed females accounted for 30.8% of all females. Freshly fed females were few, accounting for only 11.5% of the females. The half gravid and gravid females were 19.2% and 38.5% of the collections respectively.

The composition of A.gambiae and funestus mosquitoes collected from burrows at Perkerra was similar in most respects to those at Loboi except that as in the case of indoor resting mosquitoes a higher number of each species was collected at Loboi. However, a significantly higher proportion ($P < 0.05$) of unfed females of A.gambiae were collected at Perkerra (52.5%) than at Loboi (32.6%). On the other hand higher percentages of the half gravid and gravide females were collected at Loboi (24.3% and 37.0% respectively) than at Perkerra (15.3 and 22.0% for the two stages respectively). A.gambiae made up 26.2% of all the mosquitoes collected from burrows at Loboi, A.funestus was 10.4% and the remaining 63.4%,consisted of culicines.

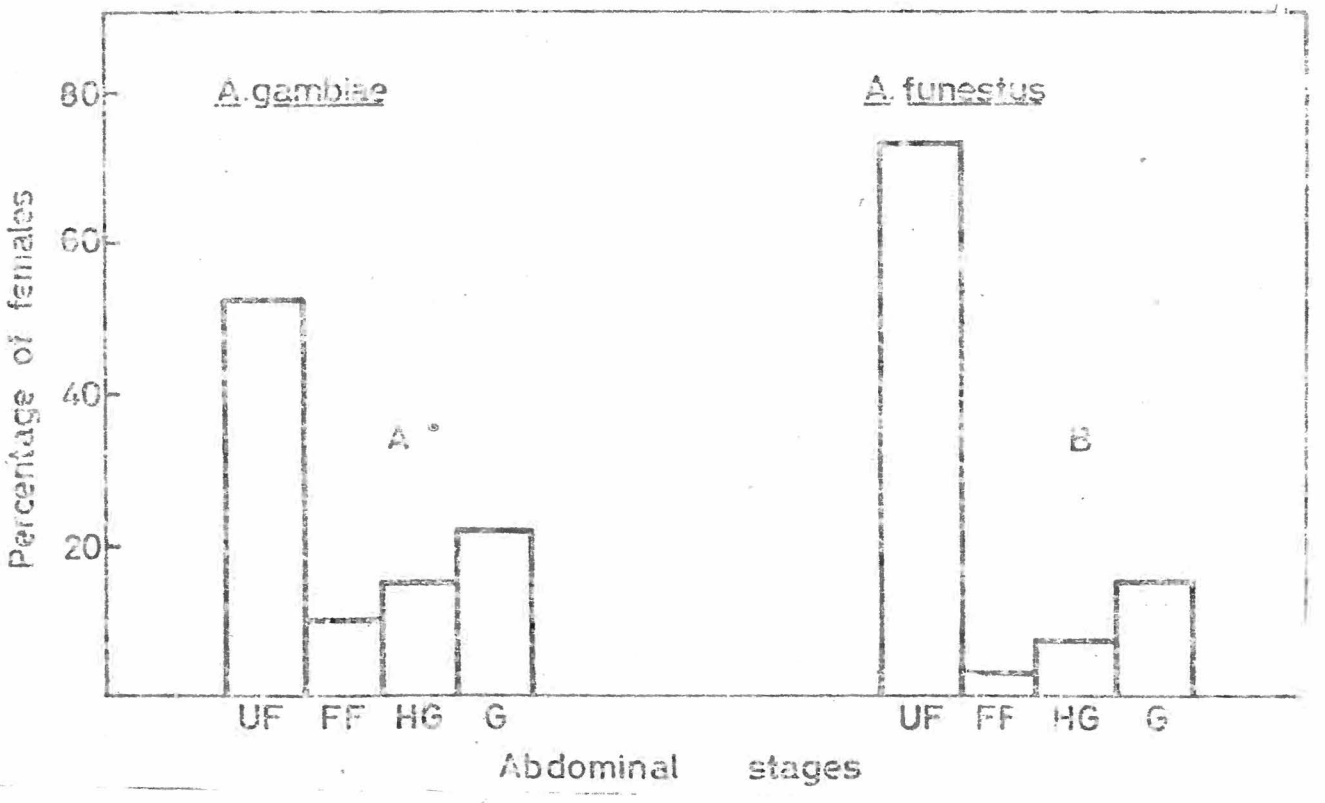


Figure 37: Percentage composition according to abdominal stages of female mosquitoes collected from animal burrows at Perkerra.

The corresponding values at Perkerra were 19.6% for A.gambiae, 7.2% A.funestus and 73.2% Culicini. The distribution of Culines collected from animal burrows on the basis of abdominal stages was similar to that of the anophelines except that there were higher percentages of males and unfed female culicines than anophelines (Table 16 A and B).

A.pharoensis was the only species found in fairly large numbers in vegetation around houses and animal enclosures. Three culicine genera Culex. Mansonia and Aedes were also collected from this resting site in small numbers. A.gambiae and funestus were completely absent. The composition of A.pharoensis and the Culicine collected in this resting site is given in Table 17 and Fig. 33.

Of 127 specimens collected, 9 (7.1%) were males and 118 (92.9%) females. The majority (48.3%)of the females were freshly fed females. Unfed females accounted for 12.7%, half gravid females 14.4% and gravid females 24.6%, of the total females collected. Analyses of A.pharoensis data, show that (a) the % of unfed and gravid females were higher in the outdoor resting site (12.7) and 24.6% respectively) than in the indoor site (0.0% and 3.5% respectively) (b) the % of freshly fed females was higher in the indoor site (82.5%) than in the outdoor site (48.3%) (Tables 15A, 17).

Table 17: Composition of mosquites collected from vegetations aroun human habitation at Loboi according to thei abdominal st

Sex/Stage	A.pharoensis		Other Species						
	NO	%		M	F	UF	FF	HG	G
MALE	9	7.1	Culex spp	6	14	6	3	3	2
FEMALE	118	92.9							
UF	15	12.7	Mansonia	0	11	0	11	0	0
FF	57	48.3							
HG	17	14.4	Aedes sp	0	4	0	2	2	0
G	29	24.6							
Total	127								

KEY. M = Male, F = Female, UF = Unfed, FF = Freshly fed, HG = Half gravid, G = Gravid.

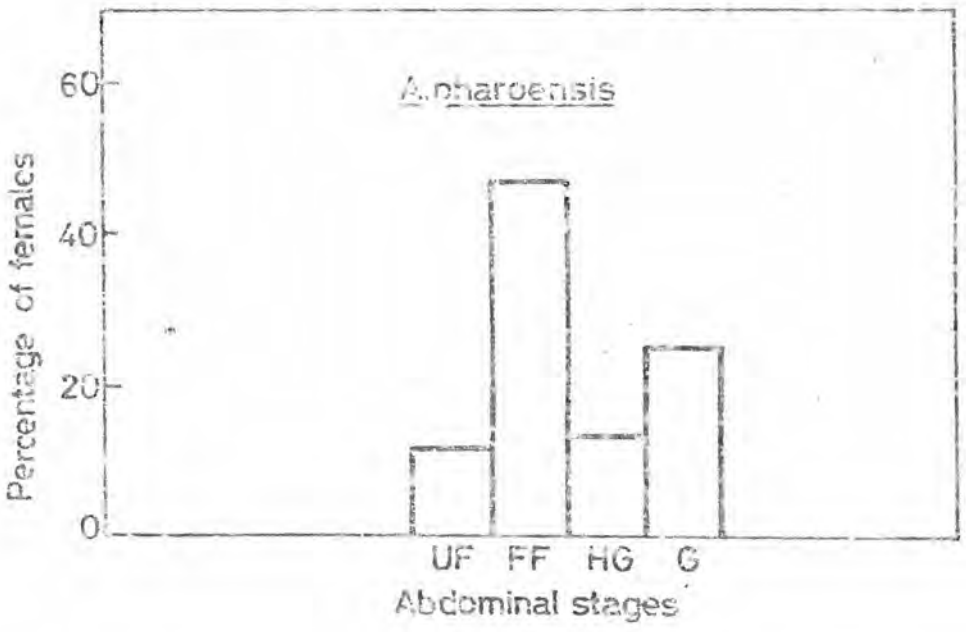


Figure 38: Percentage composition according to abdominal stages of Anopheles pharoensis collected from vegetation around animal enclosures and human habitations at Loboi.

5.3.3 Host Preferences

The results of the precipitin tests are given below.

Table 18: Summary of the Results of Blood-Meal Analyses for Host Preference Studies.

		POSITIVES					NEGATIVES	
		MAN			BOVIDS			
SPECIES	EXAMD.	+ve	% (T)	% (P)	NO	% (T)	% (P)	NO	%
A. GAMBIAE	114	93	81.6	88.6	12	10.5	11.4	9	7.9
A. FUNESTUS	72	30	41.7	58.8	21	29.2	41.2	21	29.9
A. PHAROENSIS	57	15	26.3	35.7	27	47.4	64.3	15	26.3
	243	138	56.8		60	24.7		45	18.5

KEY: % (T) = Percentage of Total

% (P) = Percentage of Positives = HBI (Human Blood Index) in man.

i.e. HBI = $\frac{\text{No of Smears with human blood x 100}}{\text{Total No of positive smears.}}$

+ve = No Positive

A total of 243 blood smears were analysed; of these, 138 (56.8%) was human blood, 60 (24.7%) contained bovine blood and 45 (18.5%) were negative (inconclusive). There were 114 A.gambiae smears; 93 (81.6%) were human blood, 12 (10.5%) bovine blood and 9 (7.9%) were negative. For A.funestus, 72 smears were analysed, 30 (41.7%) were human blood, 21 (29.2%) bovine blood and 21 (29.2%) negative. Fifty-seven A.pharoensis smears were analyzed, 26.3% were human blood, 27 (47.4%) bovine blood and 15 (26.3%) were negative.

The human blood index (HBI) was calculated for each species. As stated above, this is the percentage of the positive smears that contained human blood and is a measure of the degree of antthropophily of the species concerned. A.gambiae had an HBI of 88.6%, A.funestus 58.8% and A.pharoensis 35.7%. Applying the same calculations to the positive smears with bovine blood the degree of zoophily of each species could be estimated. The respective values for A.gambiae, A.funestus and pharoensis were 11.4%, 41,2% and 64.3%.

The negative results arose either because the smears were not properly prepared or because the mosquitoes had fed on organisms other than those tested for. Considering the high percentages of negatives in A.funestus and A. pharoensis, at least some of them must have been due to the second reason.

5.4 Discussion

5.4.1 Biting Activity

The biting activity of the three major anopheline species, A.gambiae, A.funestus and A.pharoensis were studied between dusk and dawn since they are known to be essentially nocturnal in their habits (Haddow et al., 1947; Gillies and De Meillon, 1968). There was a close similarity between the indoor and outdoor biting cycles (Table 14 A and B), suggesting that the populations in the two environments were homogeneous. The results also show that A.gambiae and A.funestus bite more often indoors than outdoors, while A.pharoensis bites more often outdoors than indoors.

The A.gambiae results are in agreement with those of Haddow (1942) from Kisumu, Kenya, Gillies (1954, 1957) in Tanzania, Holstein (1954) in Upper Volta, Smith and Drapper (1959) in Tanzania and Krafsur (1977) in Ethiopia. However, they are in contrast with results obtained by other workers (Van Someren et al. 1958. Mutero et al., 1982; Hanney, 1960. Dunkeen and Omer, 1986).

White (1974) states that among the A.gambiae complex, A.gambiae ss. is primarily endophagic (that is, bites more frequently indoors) while A.arabiensis and the saltwater spp, A.merus and A.melas, are primarily exophagic, (bite more frequently outdoors). A.arabiensis can also be endophagic, depending on local conditions. Service (1963) found approximately equal numbers of both A.gambiae and A.funestus

biting indoors and outdoors in Kaduna, Nigeria. Most other workers, however, have found A.funestus to be more endophagic than exophagic in its biting habits (Haddow, 1942; Muirhead-Thomson, 1951 a; Gillies, 1954 a; Smith and Draper, 1959; Hanney, 1960; Krafsur, 1977).

The biting activity of A.gambiae and A.funestus was highest during the second half of the night, a pattern consistent with previous records. The peak activity for A.gambiae was between 2200 and 0100 hours, dropping gradually thereafter till 0600 hours. This agrees with the results recorded by Gillies (1957), who established a peak activity of 2200 - 0200 hours and Mutero et al. (1982), who recorded a peak activity at 2400 - 0300 hours. Other workers have also found maximum biting activity between 02300 hours and dawn, with peak around 0400 to 0600 hours, (Mattingly, 1947; Haddow et al; 1947, Hanney, 1960; Van Someren et al; 1958; Dunkeen and Omer, 1986). Krafsur (1977), in Ethiopia, found that A.gambiae biting activity increased steadly throughout the night. He noted a linear relationship between proportions of nightly totals attacking and hour of attack. Service (1963) found two peaks of A.gambiae biting activity in northern Nigeria, one between 2400 and 0100 hours and another between 0400 and 0500 hours.

A.funestus activity was more evenly spread between 2300 hours and dawn. From 2200 hours, there was a steady increase in activity, reaching a peak between 0100 and 0300 hours and dropping only slightly thereafter before dawn.

Haddow (1942) recorded the period of maximum activity for A.funestus as 0300 - 0600 hours, while Ramsey (1960) recorded 2300 - 0500 hours. Service (1963) recorded two peaks for this species: 2400 - 0200 hours and 0300 - 0400 hours. Haddow (1942) observed that the increased activity of A.gambiae and funestus at 0500 - 0600 hours was due to an influx of mosquitoes seeking daytime shelters inside houses and not necessarily an increase in feeding activity. In Lagos, Nigeria, Muirhead-Thomson (1948) observed that there was considerable exit of half gravid A.melas mosquitoes from houses at dawn which he also attributed to the seeking of outdoor daytime resting sites. Krafsur (1977) in Ethiopia found that his catches at 0600 - 0700 hours included a large proportion of gravid and partly fed individuals, suggesting that considerable inter-hut traffic occurred.

A.pharoensis had its maximum biting activity within the first four hours of the night; 82% of biting indoors and 75% outdoors occurred between 1900 and 2300 hours, with the peak around 2200 hours. The peak periods of biting activity observed for A.pharoensis indoors and outdoors were similar to those recorded by Hamon (1963) and Krafsur (1977).

5.4.2 Resting Habits

In both Anopheles gambiae and Anopheles funestus, males and females were present in daytime indoor catches and the bulk of the indoor resting females consisted of fed

individuals. These are characteristics of essentially indoor resting species (Haddow, 1942; Subra, 1980). At Loboi where the two species were collected in almost equal numbers, they constituted 82% of the total indoor collection (about 41% each), and only 36% of the outdoor collection (26% A.gambiae and 10% A.funestus). However, there was an unexpected high number of freshly fed: gravid ratio. This suggests that some indoor resting females left the house during the 48 hour-period, between their being freshly fed and gravid. Fully engorged freshly fed females should occur indoors with gravid females in a ration approximating $p^0:P^1$, where p^0 is the probability of a newly emerged female surviving through one day, = 1, and p^1 is the average daily survival rate (Krafsur, 1977).

In the present study this would give a ration of 1:0.81 and 1:0.87 for A.gambiae at Loboi and Perkerra respectively. The observed values were 1:.33 and 1:0.29, for the two locations respectively (see Tables 15A and B). These were significantly different from the expected ($p < 0.001$) and points to a considerable degree of exophily among the gravid group of indoor resting A.gambiae females. Since the daily survival rates of A.funestus were not calculated, the expected frequencies of freshly fed/gravid females could not be estimated from the observed results. However, based on the lower ratio of the two abdominal stages in this species (1.3:1) compare to that of A.gambiae (3.1), It is reasonable to conclude that the difference of the observed values from

the expected would be much less. According to Muirhead-Thomson (1948), any excess of freshly fed over gravids, assuming 2-day gonotrophic cycle, in house catches, represents the proportion that has left the house between feeding and completion of egg development. This proportion was 33.2% for A.gambiae and 15% for A.funestus at Loboi, indicating that the former was less endophilic than the latter. At the Perkerra irrigation scheme, the proportion of this incipient exophilic part of the A.gambiae population was even higher (37.9%). For A.funestus in this location, the higher value of the gravids (34.8%) over the freshly fed (30.4%) is consistent with the observations of Hocking and MacInnes (1948) and Gillies (1954 a) that some individuals which had fed elsewhere move into houses to rest during the day. However, because very small numbers of A.funestus in all abdominal stages were collected here, no strong conclusions can be based on them.

In A.pharoensis, both males and females were also present in indoor daytime collections and fed females constituted the bulk of indoor resting females. This was similar to observations in A.gambiae and A.funestus. While the male: female ratios were 1:6 and 1:5 for A.gambiae and A.funestus respectively, it was 1:10 for A.pharoensis. The ratio for A.pharoensis, coupled with the complete absence indoors of unfed females and very small proportion of gravids (3.5%) relative to freshly fed (83%) clearly showed that this species was strongly exophilic. Females entered houses only to feed and most of them (up to 79%) left the

house between feeding and completion of their egg development. This view is further supported by the higher percentage of gravid females in the outdoor collection (24.6%), relative to freshly fed females (48%), as compared with the indoor collection.

The composition of indoor resting culicines was different in many respects from those of the anophelines. The culicine male: female ratios were only 1:3 and 1:2 at Loboi and Perkerra respectively. These were significantly lower than those of anophelines. Secondly, unfed females were the highest proportion of indoor resting females with freshly fed, half gravid and gravid occuring in almost equal proportions (see Tables 15 A and B). These results suggest a high degree of endophily. The mosquitoes entered houses for feeding and resting. More than 90% of the Culicine collected indoors was C.quinquefasciatus, which is well-known for its house-haunting habits (Meillon et al., 1967; Subra, 1980). However, more than 60% of the mosquitoes collected from outdoor resting sites (animal burrow) consisted of this same species. This outdoor collection was predominated by males and unfed females, with only a few fed females.

These apparently conflicting habits of this species are explained by the observation of Subra (1980) that the species is both endophilic and exophilic, the same female may exhibit both tendecies in the course of one gonotrophic

cycle. He noted that newly emerged individuals take shelter in both indoor and outdoor sites before taking their first bloodmeal. While some females which have fed indoors may leave the house to complete their development outside, others which fed outside may move indoors to rest and complete their egg development.

5.4.3 Host Preferences

The results of precipitin tests showed that A.gambiae in Marigat division was predominantly anthropophilic with a human blood index (HBI) of 88.6%, while A.funestus was only moderately so with a HBI of 59.8%. Observations on the feeding behaviour of these two species throughout much of their range have demonstrated a strong tendency for human blood, even in areas long under insecticidal attack (Bruce-Chwatt et al., 1966). Davidson and Drapper (1953) found more than 90% of their A.gambiae catches in parts of East Africa positive for human blood. Gillies (1954 b, 1956) at Muheza, Tanzania got a HBI of 92% while Arap Seroney et al. (1985) obtained 90.3% in Kisumu Kenya. In a review of the subject, Bruce-Chwatt and Guckel (1960) noted that the range in most parts of Africa is 41 - 86%. Figures as high as 100% have been recorded (White, 1974; Krafsur, 1977). On the other hand, exceptionally low indoor HBI values of 59% (White and Rosen, 1973) and 28 (Service, 1970 a) have been obtained in areas of northern Nigeria where cattle outnumbered man inside houses at night.

The value of 58.8% obtained for A.funestus here was lower than those recorded by many other workers, including 98% by Haddow (1942) in Kisumu Kenya; 97% in Liberia, 94% in Ghana and 85% in Northern Nigeria by Bruce-Chwatt and Gockel (1960); and 100% by Krafsur (1977) in Gambela, Ethiopia. Low %s were obtained by Symes (1932), 60%, Kaurtze and Symes (1933), in Kenya, 57%; Bruce-Chwatt and Gockel (1960) in Upper Volta, 24 - 26%; and De Zulueta et al. (1963) in Uganda, 42%.

A.pharoensis collected in the present study showed marked zoophily with 64.3% of the catches containing bovine blood and only 35.7% containing human blood. From indoor catches, Symes (1931 a) in Kenya found 48% containing human blood, Smith (1955 b) also found 48% of indoor collections on Ukara Island, Tanzania to contain human blood. However, outdoor collections gave lower proportions of man-positives e.g Bruce-Chwatt and Gockel (1960) got 5 - 20% from outdoor catches in West Africa and Smith (1958) got 0 - 9% in the low lands of Kenya. Most of the specimens tested in the present study were collected from outdoor sites (vegetation around animal enclosures). The value of 35.7% positive for human blood is higher than those from other outdoor collections.

CHAPTER 6

MALARIOMETRIC STUDIES

6.1 Introduction

Malariometric surveys were carried out in 1987 in order to:- (i) determine the rates of infection with malaria parasites or sporozoite rates of the major anopheline species found in the study area. (ii) assess the prevalence of malaria, that is, the percentage of the population infected among different age groups of school children in the area.

Infants and children are usually better indicators of the prevalence of malaria in any population than the adults because of their lower natural immunity to the disease (W.H.O, 1961, 1975 b, 1980, 1987). In this study therefore the collection of blood smears for examination for malaria parasites was concentrated on children.

6.2 Materials and Methods

6.2.1 Dissection of Mosquitoes for Sporozoites

The salivary glands of female mosquitoes were dissected between April and September 1987. Since it was not possible to do the dissections over the whole year, this period was chosen because it covered both the period of

highest mosquito densities, April-September, as well as the period of highest malaria incidence, July-September, as indicated by the results of the pre-study survey.

The method outlined by the W.H.O. (1975 a) was followed. The slides were examined immediately after preparation under high power for the presence of sporozoites. In order to confirm the observations made on the fresh slides and to preserve them for future references, some of the slides were left to dry, then fixed with methanol and stained with Giemsa. These were then examined under oil immersion.

A total of 1670 Anopheles mosquitoes were dissected April - September 1987 (as described in Section 3.4), 1,200 of these were A. gambiae s.l. while the remaining 470 were A. funestus. A. gambiae was collected from two locations, Kapkuikui village in Loboi and Perkerra irrigation scheme, while A. funestus was only collected from the former habitat.

6.2.2. Collection and Examination of Blood Smears from schools

Blood smears were collected at three different times of the year. The first was in March which was the end of the long dry season and the beginning of the long rains. The second was in July which was the end of the long rainy season and the beginning of the cool dry period, and the third

collection was in October just before the short rains (see Table 3, Section 3.3.3). Three primary schools were used;

(a) Perkerra Primary School, situated in the middle of the Perkerra irrigation scheme, with an enrolment of 350 pupils.

(b) Kapkuikui Primary School, situated in Kapkuikui village in Loboi location, at the edge of the Loboi swamp, with a population of 100 pupils.

(c) Loboi Primary School, situated at Tingttiyon village about 3km from the Loboi swamp, with 250 pupils.

The first two surveys in March and July covered the three schools. Blood smears were taken from all pupils in each school whose ages were between 5 and 20 years. Based on information obtained from these two surveys, the third survey in October comprised infants, aged 0 - 22 months, pre-school age children, aged, 2 - 4 years, and school children, aged 5 - 15 years. Loboi Primary School was not included in this third survey.

During each survey, blood smears were collected from the index finger of pupils and prepared for examination in accordance with W.H.O guidelines (W.H.O, 1961, 1975 a). Both thick and thin smears were made on each slide. The staining solution (Giemsa) was prepared on each occasion just before use by mixing the stock solution (which was prrpared one week in advance) with buffered distilled water (pH 7.2) in

a 1:20 ratio. Thin smears were fixed in absolute methanol.

Examination of Slides

In routine malaria surveys, an examination of 100 microscopic fields under oil immersion for each slide (approximately 5 minutes of examination) is the standard practice (Bruce-Chwatt, 1985). In this study, however, 200 microscopic fields were examined on each slide (thick smear) under oil immersion. This was to ensure that scanty infections were not missed out. After examination, the slides were scored as positives and negatives. The thin smear of each positive slide was then used to identify properly the Plasmodium species present. An estimate of the degre of infection or parasite density was made on each positive slide by a parasite count. The procedure adopted was to count the number of parasites and leucocytes in the thick smear until 200 of the latter had been counted. The number of leucocytes in an average human being is estimated at 5,000 - 11,000 (average 8,000) per cubic millilitres of blood. The parasite count, or parasite density, was then calculated as:-

$$\frac{\text{No. of Parasites counted} \times 8000/\text{mm}^3}{200}.$$

If this value exceeded $1000/\text{mm}^3$, that is, 25 parasites per 200 leucocytes counted, the infection was regarded as heavy.

The presence or absence of the sexual forms of the malaria parasites called gametocytes in any blood smear was also noted.

6.2.3 Analysis of Malaria cases at the Marigat Rural Health Centre

The incidence of malaria in the entire population of Marigat division was estimated by reviewing all cases of clinical malaria treated monthly at the Marigat Rural Health Centre between 1982 and 1986. The centre was the biggest medical establishment in the division and catered for an estimated 21,000 people (1983 figures). The analysis involved the determination of the percentage of total monthly attendance which was diagnosed and treated as clinical malaria.

6.3 Results

6.3.1 Infection Rates in Mosquitoes

Of the 555 gambiae collected and dissected from Kapkuikui, Lobei, 16 carried sporozoites, giving an overall sporozoite rate of 2.9%. The rate of infection was lowest in the months of April and May (2.5%) and highest in the months of August and September (3.3%). Of the 470 A.funestus dissected, 9 carried sporozoites, giving an overall rate of 1.9%. Infection was lowest in April (1.3.%) and highest in July (2.5%).

From the Perkerra irrigation scheme, 23 of the 645 A.gamoiae dissected were positive for malaria parasites, giving an overall sporozoite infection rate of 3.6%. The monthly rates ranged from 2.5% in September (lowest) to 4.3% in July (highest).

The results are summarized on Table 19. At Perkerra, infection rates were high from April to July (mean = 3.9%), then there was a considerable decrease in August and September (mean 2.7%). On the other hand at Loboi the rates were relatively low between April and June (mean = 2.6%) and then increased between July and September (mean = 3.3%). In each case the period of increase in infection rates coincided with the period of relative low mosquito density while the period of low infection rates coincided with the period of relative high mosquito density (c.f. Table 2, section 2.3.2). The infection rate in A.funestus was lower than in A.gambiae. There was no significant difference between the lowest and highest rates in each species in the two locations. There was also no significant difference between the mean infection rates of A.gambiae and A.funestus ($p > 0.05$).

Table 19: Parasite Rates in Mosquitoes April - September, 1987.

	PERKERRA			LOBOI			LOBOI		
	A. gambiae			A. gambiae			A. funestus		
MONTHS	NO DISSECTED	NO POSITIVE	PARASITE RATE	NO DISSECTED	NO POSITIVE	PARASITE RATE	NO DISSECTED	NO POSITIVE	PARASITE RATE
APRIL	30	1	3.3%	80	2	2.5%	80	1	1.3%
MAY	120	5	4.2	80	2	2.5	60	1	1.7
JUNE	133	5	3.8	150	4	2.7	90	2	2.2.
JULY	140	6	4.3	90	3	3.3	80	2	2.5
AUG.	142	2	2.8	90	3	3.3	60	1	1.7
SEPT.	80	4	2.5	60	2	3.3	100	2	2.0
TOTAL	645	23	3.6%	555	16	2.9%	470	9	1.9%

6.3.2 Crude Inoculation Rates.

In order to assess the consequences of the seasonal changes in Anopheles densities to the human population at risk, the average number of bites per person per night and the average daily inoculation rates were calculated. The bites per person per night were computed as the product of the density of mosquitoes per house per night and the proportion freshly fed, divided by the average number of occupants per house. The crude inoculation rate is defined as the mean number of sporozoite-laden bites per person per night, or as the relative proportion of the human population receiving an infective bite per night (Bruce-Chwatt, 1985). It was calculated as the product of the daily biting rate and the sporozoite rate. The daily inoculation rate was multiplied by the number of days in any month to give the monthly inoculation rate (Krafsur, 1977).

The values for Iboi and Perkerra appear on Tables 20 and 21 respectively. Since the sporozoite rates were measured for only six months (April - September), the inoculation rates could only be calculated for these months. The average indoor resting densities from which mean biting rates were calculated, were not adjusted to compensate for escapees during collection or for exophily. Since the number escaping was low because adequate precautions were taken during sampling, the results would not be affected. The biting rates were also calculated from freshly fed females, whereas exophily in the two species concerned was shown to

be essentially by the gravid females (section 5.4.2).

On the assumption that infected mosquitoes feed randomly, the average daily inoculation rate for A.gambiae at Loboi was highest in May - July and lowest in April. At Perkerra, the highest values for the daily inoculation rates were obtained in July - September and the lowest in April. For A.funestus, the highest rates were obtained in August and September, the values for the other four months were similar. There was no significant difference between the highest and lowest rates for each species in the two locations ($p > 0.05$) but the mean rates in A.gambiae were significantly higher than the mean rates in A.funestus ($p < 0.01$).

Table 20: Estimated Crude Daily Inoculation Rate at Loboi.

ANOPHELES GAMBIAE						ANOPHELES FUNESTUS				
MONTH	DENSITY HUT/ NIGHT	PROP FRESHLY FED	BITES/ MAN/ NIGHT*	SPOROZ. RATE	INOC. RATE**	DENSITY HUT/ NIGHT	PROP FRESHLY FED	BITES/ MAN/ NIGHT*	SPOROZ RATE	INOC. RATE**
JAN	3.3.	0.63	0.80			0.8	0.75	0.20		
FEB	2.8	0.64	0.60			1.4	0.43	0.20		
MAR	7.7	0.58	1.49			3.8	0.37	0.47		
APR	9.1	0.36	1.09	0.025	0.027	7.3	0.33	0.80	0.013	0.010
MAY	46.1	0.49	7.53	0.025	0.188	4.0	0.38	0.51	0.017	0.009
JUN	12.2	0.49	1.99	0.027	0.054	4.1	0.32	0.44	0.022	0.010
JUL	14.7	0.50	2.45	0.032	0.078	3.0	0.40	0.41	0.025	0.010
AUG	8.4	0.31	1.43	0.033	0.047	14.3	0.23	1.11	0.017	0.019
SEP	7.1	0.52	1.23	0.033	0.41	797	0.48	1.24	0.020	0.025
OCT	6.0	0.58	1.16			17.9	0.20	1.19		
NOV	3.5	0.69	0.81			47.9	0.05	0.80		
DEC	5.3	0.68	1.20			12.0				
MEAN	10.60	0.56	1.82	0.029	0.053	10.4	0.35	0.71	0.019	0.0133

* Computed as (Density/hut/night) x (proportion freshly fed) divided by average number of occupants per hut (3.0)

** Computed as (Bites/man/night)x Sporozoite Rate

Table 21: Estimated Crude Daily Inoculation Rate at Berkeria

	ANOPHELES GAMBIAE				
	DENSITY HUT.NIGHT	PROPORTION FRESH FED	BITES/ MAN/NIGHT*	SPOROZOITE RATE	INOCULATION RATE**
JAN	0.6	0.27	0.15		
FEB	0.4	0.00	0.00		
MAR	0.8	0.63	0.19		
APR	1.1	0.18	0.08	0.037	0.003
MAY	1.4	0.14	0.08	0.042	0.003
JUN	3.5	0.60	0.81	0.038	0.031
JUL	8.9	0.42	0.44	1.42	0.052
AUG	19.8	0.48	3.66	0.028	0.102
SEP	22.3	0.81	5.23	0.025	0.131
OCT	3.6	0.47	3.18		
DEC	2.5	0.56	0.53		
MEAN	6.40	0.46	1.33	0.036	0.049

* Computed as (Density/hut/night) x (prop. fresh fed) divided by average No of occupants per hut (2.6).

** Computed as (Bites/man/night) x Sporozoite Rate

6.3.3. Parasite Rates in School Children.

The detailed results of the malaria survey among school children are contained in Appendix 2. A summary of the results is given in Tables 21 - 23 for the months of March, July and October respectively.

The overall infection rate for each school was calculated as the percentage of the school population showing malaria parasites in their blood, that is,

$$\text{Rate} = \frac{\text{Total Positive in the school}}{\text{Total Examined in the school}} \times 100$$

The values were 15.1%, 11.5% and 3.5% for Perkerra, Kapkuikui and Loboi Primary schools respectively in March and 15.3%, 16.9% and 4.8% for the three schools respectively in July. Thus in the two schools near the Loboi swamp (Kapkuikui and Loboi Primary Schools) the infection rates were higher in July than in March whereas at the Perkerra Primary School, located on the irrigation scheme, the rate was higher in March than in July (Tables 22 and 23). There was, however, no significant difference between the higher and lower rate in any of the three schools. The rates were comparable at Perkerra and Kapkuikui during the months but were lower at Loboi Primary School. There was no significant difference between the infection rates at Perkerra and Kapkuikui Primary Schools during both months ($p > 0.01$). However, there

was a highly significant difference between infection rates at Perkerra and Lobei Primary Schools both in March (X^2 = 17.73, $p < 0.001$) and in July (X^2 = 9.54, $p < 0.01$), the difference between rates at Kapkuikui and Lobi Primary Schools were significant in March (X^2 = 6.25, $p < 0.05$), July (X^2 = 10.13, $p < 0.001$).

Table 22: Summary of the results of Malaria Surveys among Primary School children in Marigot division, March 1987.

	PERKERRA P. SCHOOL.			KAPKUIKUI P. SCHOOL.			LOBOT P. SCH.		
AGE GROUPS	NO EXAM.	NO POSITIVE	PARASITE RATE*	NO EXAM.	NO POSITIVE	PARASITE RATE*	NO EXAM.	NO POSITIVE	PARASITE RATE*
5-9yrs.	73	24	5.9% (24.0)	39	5	[illegible] (15.4)	81	3	1.8
10-14yrs.	179	28	8.6 (15.6)	40	2	2.1 (5.0)	93	1	1.3
15-19yrs.	66	2	0.62 (3.0)	7	-	-	60	1 (1.3)	0.44
20+yrs	-	-		10	3	3.1 (30.0)	4	-	-
TOTAL	324	49	15.1%	96	11	11.5%	226	8	3.5%

* Unbracketed figures = Percentage of Total = Parasite Rates

Bracketed figures = Percentage of age group infected.

Table 23: Summary of the results of Malaria Surveys among Primary Schools children in Marigat division, July 1987.

	PERKERRA P. SCHOOL.			KAPKUIKUI P. SCHOOL.			LOBOI P.SCH.		
AGE GROUPS	NO EXAM.	NO POSITIVE	PARASITE RATE	NO EXAM.	NO POSITIVE	PARASITE RATE	NO EXAM	NO POSITVE	PARASITE RATE
5-9yrs.	92	17	5.0 (18.5)	49	8	9.0 (16.3)	32	2	1.0 (6.3)
10-14yrs.	172	23	6.7 (13.4)	24	6	6.7 (25.0)	101	3	2.9 (5.9)
15-19yrs.	77	6	1.8 (7.8)	9	1	1.1 (11.1)	70	2	1.0 (2.9)
20+yis.	1	-	-	7	-	-	4	-	-
TOTAL	342	46	13.5%	89	15	16.9%	207	10	4.8%

* Uncracketed figures = Percentage of total + Parasite Rate.
Bracketed figures = Percentage of age group Int.

Table 24: Summary of the Results of Malaria Surveys among Primary School children in Marigat division, October 1987.

PERKERRA PRI. SCHOOL				KAPKUIKUI PRI SCHOOL		
AGE GROUPS	NO EXAM.	NO POSITIVE	PARASITE RATE	NO EXAM.	NO POSITIVE	PARASITE RATE
0-11 MONTHS	9	3	2.1 (33.3)	5	2	1.6 (400)
12-22 MONTHS	17	7	4.8 (41.2)	10	2	1.6 (20.0)
2-4 yrs.	34	9	6.2 26.5)	18	6	2.3 16.7
5-9 yrs.	63	18	12.4 (28.6)	50	3	2.3 (6.0)
10-14 yrs.	12	2	1.4 16.7)	40	2	1.6 (5.0)
15-19 yrs.	10	0	0	5	0	
20+ yrs.	-	-	-	-	-	-
TOTAL	145	39	26.9%	128	12	9.4%

* Unbracketed figures = Percentage of Total = Parasite Rates
Bracketed figures = Percentage of age group infected

The parasite rate in each age group was calculated from the formula given above by substituting the number positive in the school with the number positive in the age group. This gave the proportion of the overall parasite rate atributable to each age group. These are the unbracketed figures in the "Rates" columns of Tables 22-24. However, since different numbers of people were examined in each age group, these rates did not indicate clearly which age group was more prone to malaria than others. To establish this, the percentage positive for the number of people examined in each age group was calculated by substituting the number examined in the school with the number examined in each age group in the above formula. These are the figures enclosed in brackets on Tables 22-24. It can be seen from these that the 5-9 year olds were the most susceptible to malaria infection followed by the 10-14 year olds. The least susceptible were the 15-19 year age group. The number of people examined under the 20 years and above age group was very small and except for the 3/10 rate at Kapkuikui in March, no other case of the disease was recorded in this age group.

These observations of higher infection rates among younger age groups prompted the inclusion of infants and pre-school age children and the exclusion of older children of 15 years and over in the last survey carried out in October 1987. Loboi Primary school was also excluded in this last survey. The results are given on Table 24. The overall

percentage infection rates were 26.9% and 9.4% for Perkerra Primary school and Kapkuikui Primary school respectively. Thus at Perkerra, infection of school children with malaria parasites was highest in October (26.9%) followed by March (15.1%) and lowest in July (13.5%) At Kapkuikui (Lobei) on the other hand the infection rate was highest in July (16.9%), followed by March (11.5%) and lowest in October (9.4%). In October, the infection rate at Perkerra was significantly higher than that of March (x^2 = 9.11, $p < 0.01$) and July (x^2 =11.86 $p < 0.001$). There was also a significant difference between the infection rate at Perkerra and that at Kapkuikui at this time (x^2 = 12.61, $p < 0.001$). Just as in the two previous surveys, the rate of infection was higher in the younger age groups and tended to decrease with age, as is shown by brackets in Tables 21-23. The October rate at Perkerra was also significantly higher than those recorded at Kapkuikui in March and July.

The detailed tabulation of the results given in Appendix 2 shows, that there were a few cases of gametocytes in the blood of infected individuals as well as some cases of heavy infections. There were 5 cases of gametocytes in the blood in March and 2 cases in July, all of them recorded in Perkerra. There were 2 cases of heavy infections (above 1,000 parasites/mm^3 of blood) in March at Perkerra and none

at the other two schools. But in July there were altogether 24 cases of heavy infections, 14 at Perkerra, 9 at Kapkuikui and 1 at Loboi. Eleven of the cases occurred among the 5-9 year old age group, 11 among the 10-14 year olds and the remaining 2 among the 15-19 year olds. there were 2 and 1 cases of heavy infeation at Perkerra and Kapkuikui respectively in October and no case of gametocytes in either school. Only Plasmodium falciparum was encountered during the three surveys.

6.3.4. Incidence of Malaria in the Population

The results are shown on Table 25. On the average, between 153 - 715 cases of malaria were treated every month, representing 40-69% of all attendances at the hospital. On an annual basis, malaria accounted for 51 - 56% (mean 53.5%) of the total attendance. February to April showed the lowest incidence of malaria (mean 46%) while July-September showed the highest incidence (58.7%), over the 5 - year period.

TABLE 25: Incidence of Clinical Malaria recorded at the Marigat Rural Health Centre, 1982 - 1985

	1982			1983			1984			1985			1986			
MONTH	TOT ATT.	CL MAL	% MAL	TOT ATT.	CL MAL	% ATT	TOT MAL	CL MAL	% ATT	TOT MAL	CL MAL	% ATT	TOT MAL	CL MAL	% MAL	MONTHLY AVE. %
JAN	496	273	55	559	285	51	498	215	45	896	520	58	706	339	48	51.4
FEB	500	260	52	500	225	45	553	260	47	678	346	50	658	302	46	48.0
MAR	537	290	54	480	221	46	475	199	42	N.A	-	-	655	275	42	46.0
APR	411	189	46	383	153	40	500	245	49	N.A	-		483	203	42	44.3
MAY	429	210	49	446	196	44	602	349	58	N.A	-	-	646	232	36	50.3
JUN	438	218	50	559	285	51	577	334	58	N.A	-		817	425	52	52.8
JUL	557	362	65	435	209	48	563	331	59	697	590	61	1093	655	60	58.6
AUG	543	375	69	583	309	53	579	359	62	1099	646	64	1153	715	62	62.0
SEP	488	258	53	563	327	58	579	324	56	905	498	55	911	510	56	55.6
OCT	542	297	55	911	510	56	609	329	54	900	522	58	821	402	49	54.4
NOV	556	328	59	687	357	52	866	433	50	682	354	52	966	483	50	52.6
DEC	446	222	50	485	262	54	803	410	51	500	205	41	929	446	48	48.8
TOTAL	5943	3282	55.2	6591	5338	50.6	7184	3788	52.7	6537	3681	56.3	9838	5078	51.6	52.1

KEY:

TOT.ATT = TOTAL ATTENDANCE; CL. MAL = CLINICAL MALARIA

% MAL = PERCENTAGE MALARIA; N.A. = NOT AVAILABLE.

6.4 Discussion

6.4.1 Infection Rates in Mosquitoes

The sporozoite rates in the mosquitoes were measured in the course of this study between April and September which included most of the rainy season, April - June, and the cool dry period following it, July - September. At Loboi the sporozoite rates in A.gambiae increased steadily from 2.5% in April to 3.3% in September. At Perkerra, the highest rates were obtained between May and July (Mean 4.1% and the lowest in September (2.5%). This time of the year, April-September, was the most conducive to mosquito breeding and survival as shown on Tables 2 and 10. The variations in the sporozoite rates could not therefore be attributed to differential survival rates as was observed by Krafsur (1977) in Gambela, Ethiopia. On the other hand, the period of high sporozoite rates in each location coincided with the period of relatively low mosquito density and vice versa. Thus, there was an inverse relationship between population size and sporozoite rate. This relationship was however, not significant at both locations ($p > 0.05$). According to Muirhead-Thomson (1948) and Gillies (1954 c) large populations usually consist of young females, consquently, the seasonal peak is associated with low infection rates. The rates increase as the population drops at the end of the rains.

Sporozoite rates obtained by earlier workers in many parts of Africa were generally higher than those obtained

Examples of the older values include 10% obtained by Muirhead-Thomson (1948) for the Lagos area in Nigeria, 14.6% by Davidson (1955) in Uganda and 9.4% by Muirhead-Thomson (1951 a) in coastal Tanzania. The more recent figures are 2.2% by De Zulueta et al. (1963) in Uganda; 0.1- 0.7% by Smith (1964) in Umbugwe, Tanzania; 4.2%, 0.32% and 2.7% by White et al. (1972) for A. gambiae species A, B and S.1. respectively in Tanzania, and 0.38% in the dry season and 5.4% in the rainy season by Krafsur (1977) in Ethiopia. The reason for the reduction in infection rates over the years must be related to increased usage of anti-malaria drugs. In all cases the samples were taken mainly from infants and school age children.

The sporozoite rates in A. funestus were generally lower than those of A. gambiae. The lowest values were obtained between May and July (1.0%) while the highest value was in September (2.5%).

6.4.2 Crude Inoculation Rates

Seasonal changes in the crude inoculation rates are the results of changes in the population densities of the mosquitoes and their age structures, which may affect the sporozoite rates. The results indicate that the inoculation rates depended more on the changes in the mosquito densities. The months with higher mean densities per hut per nigh had higher inoculation rates

irrespective of the relative values of the sporozoite rates (Tables 20 and 21). The very dry months of December to February, with greatly reduced densities per house per night must be periods of very low malaria transmission. The major biological factor responsible for this is probably the very reduced survival rates of the 4th instar larvae and pupae (see Tables 6 and 7 and Fig. 27), as well as the lower adult survival rates (Tables 10 and 11), due to less favourable environmental conditions. The human population at Loboi was thus highest at risk of infection between April and July and least at risk between December and February form A.gambiae.

During the period of heaviest inoculation in May, with a daily inoculation rate of 0.188, it would take only 5.3 days for everybody in a house (average number of occupants at Loboi =3) to get at least one infective bite. In April, with the lowest inoculation rate of 0.027 among the months measured, it would take 37 days for every occupant of the house to get at least one infective bite from a sporozoite-laden A.gambiae. The maximum number of days it would take to acquire an infective bite is obviously higher than 37 between December and March but these had not been calculated since the sporozoite rates for those months were not determined.

At the Perkerra irrigation scheme the period of highest malaria transmission, with the highest crude inoculation rates was July - September; and again, based on the values of the

mean mosquito density/house/night, December to March was the period of lowest transmission. At the height of transmission in September (daily inoculation rate=0.131), it would take 7.6 days for every occupant in a house ((average of 2.6 persons per hut) to acquire an infective bite from A. gambiae. In April, with an inoculation rate of 0.026 it would take 38.5 days. In February, the mosquito density was so low that the proportion of freshly fed mosquitoes dropped to zero, the mean crude inoculation rate was also zero.

A.funestus was found in appreciable numbers only in Loboi. Its densities and therefore biting in January - July were considerably lower than those of A.gambiae but sometimes exceeded them in August - December. In September, the month with the highest crude daily inoculation rate for this species (0.025), it would require 40 days for every occupant of a house (average 3 occupants/hut to acquire an infective bite from A.funestus whereas in May, with a rate of 0.009 it would take 111 days to get such an infective bite. Krafsur (1977) obtained crude daily inoculation rates of 0 in March/April to 0.13 (i.e one infective bite per occupant in 7.7 days) in September for A.gambiae also 0 in March to 0.97 (one infective bite per occupant in 1.03 days for A.funestus in November in Gambela, Ethiopia.

The crude daily inoculation rates obtained in this study were high enough for each unprotected inhabitant of the study area to acquire at least one infective bite in a year. This was particularly evident in Loboi where A. funestus densities began to rise when those of A. gambiae declind. The inhabitants were at a high risk of acquiring sporozoite-laden mosquito bites in April - December; At Perkerra A. funestus was virtually absent throughout the year and A. gambiae was the sole malaria vector. At Loboi, however, the two species were present in approximately equal numbers and since they reach their maximum densities and crude inoculation rates at different times of the year, A.funestus must be considered important in maintaining a high rate of malaria transmission all year round. Alone, its role as a Vector must be minimal because of its lower inoculation and sporozoite rates.

6.4.3 Parasite Rates in School Children

Malaria infection rates among school age children was high at both Perkerra and Kapkuikui Primary Schools during three different surveys in March, July and October. The pattern of malaria transmission in the study area obtained from the School Surveys is highly consistent with that determined by the study and analysis of mosquito densities, sporozoite and inoculation rates, etc. Thus at Kapkuikui Primary School, located on the Loboi swamp, the highest infection rate (16.9%) was recorded in July. Similarly the highest inoculation rates in A.gambiae (mean=0.107) was

recorded in May - July in this area. At the Perkerra Primary School, on the Perkerra irrigation scheme, on the other hand, the highest infection rate (26.9%) was obtained in October which also tallies with the highest inoculation rates (mean=0.098) in July - September.

Significantly lower infection rates were obtained at Loboi Primary School, located at Tingttiyon village, than at the Perkerra Primary School both in March and July ($P<0.01$). Similarly the infection rates in this School was significantly lower than those obtained at Kapkuikui Primary School ($P<0.01$). These highly significant differences are hard to explain, considering that mosquito vectors were equally abundant at Tingttiyon as in Kapkuikui (see Table 8) and the pupils in the two schools were drawn from the same villages and locations. There is a dispensary which is nearer to Loboi Primary School (about 300 metres) than to Kapkuikui Primary School (about 3km) and it is possible that the lower infection rates in the former school was due to more regular anti-malarial treatment.

All the cases of gametocytes in the blood were recorded at Perkerra and Kapkuikui Primary Schools in March and July. Gametocytes are he sexual forms of the malaria parasite and it is in these forms that the parasite becomes infective to mosquitoes, when they are ingested in the bloodmeal. Thus, the presence of gametocytes in the blood is a strong indication of active transmission of malaria in the area concerned.

6.4.4 Incidence of Malaria in the Population

The records of clinical malaria cases at the Marigat Rural Health Centre, also fit into the overall epidemiological pattern of high malaria transmission throughout the year with the peak between May and December. These records also show that malaria accounts for between 51 and 56% of all sickness treated annually in the Centre. The lower averages recorded for March/April relative to the other months are probably due to two main reasons. (1) Survival rates for both larvae and adults are greatly reduced between January and February due to adverse environmental conditions. This means that sporozoite-laden females do not appear in substantial numbers until mid-April, one month after the onset of the rains. (2) April is the busiest month for agriculture in the area and many farmers would readily postpone going to the hospital for medical treatment for as long as they are able to farm.

6.4.5 Impact of the Perkerra irrigation scheme on Mosquito breeding and Malaria transmission

6.4.5.1 Impact of irrigation on mosquito breeding

A comparison of the Perkerra irrigation scheme area and the non-irrigated area Endau village shows that mosquito abundance was significantly higher at the former. At Endau where mosquito breeding depended entirely on local rainfall,

A.gambiae was completely absent between January and April and was found in appreciable numbers only between May and August, with a peak in July. At Perkerra, on the other hand, A.gambiae was collected throughout the year, but especially between April and December, with the population peak in September. The ratio of this species collected from the two locations was 3:1. There was also more A.funestus and culicine species at Perkerra than at Endau although for A.funestus the numbers collected from both locations were too small for statistical analysis. These findings are in agreement with the observations of several workers who have stated that irrigation promotes mosquito breeding (W.H.O., 1967, Surtees, 1970 a; Chandler and Highton, 1975; Simpson, 1975; Chandler, 1976). In terms of species diversity there was no difference between the irrigation scheme area and the non-irrigated village.

However, a comparison of the irrigation scheme area and the Loboi swamp shows more mosquitoes (both species and numbers) were breeding in the swamp than in the irrigation scheme. All the 17 species of mosquitoes collected and identified in this study were found to breed in the swamp, but only 5 of them were found in the irrigation scheme. More individuals of every species were collected at Loboi than at Perkerra. For example, the four major species encountered, A.gambiae s.l., A.funestus, A.pharoensis and C quinquefasciatus were collected in the following ratios at Perkerra and Loboi (Kapkuikui) respectively:

A.gambiae	1:1.7
A.funestus	1:53
A.pharoensis	0:63
C.quinquefesciatus	1:13

Thus both in terms of species diversity and the relative numbers of individual species the swamp was more productive than the irrigation scheme (see also Tables 1 and 2, Chapter 3). Further more, the studies of Surtees (1970 a), Chandler and Highton (1975) and Chandler (1976) at the Ahero irrigation scheme in Kenya, and those of Heathcote (1970), Surtees (1970 b) and Mogi et al. (1984, 1986) in different parts of south east Asia indicate that mosquito breeding at the Perkerra irrigation scheme was minimal compared with other irrigation schemes, both in respect of species diversity and relative abundance. For example Surtees (1970 a) recorded 12 species, 4 anopheline and 8 culicine, as breeding in the Ahero irrigation scheme.

As has already been pointed out, the fast flow of water in the irrigation canals and the practice of intermittent irrigation rather than prolonged flooding of cultivated fields are mostly responsible for this relative paucity of mosquito species and numbers. In addition, the practice of regular clearing of vegetation from the canals, apart from ensuring the fast flow of water, also made them particularly unsuitable for the breeding of species such as

A.funestus and A.pharoensis which require vegetation in their breeding sites.

The Perkerra irrigation scheme therefore offers a good example of where irrigation practices, involving environmental manipulations, directly reduce the diversity and numbers of mosquitoes capable of breeding in it. Potential snail vectors of schistosomiasis are also completely absent from the scheme for the same reasons. It must be noted that vector control was not the aim of the irrigation board in introducing these environmental manipulations. The primary aim was water conservation. The water level of the Perkerra river is low, especially during the long dry period, and the intermittent irrigation system is aimed at minimizing water usage (Annon., 1987 b). Only crops which can survive on this type of irrigation are planted on the scheme. Even the constant weeding of the water channels is aimed primarily at ensuring the non-obstruction of water flow. The highly desirable effects of these practices on vector populations strongly suggest that they should be positively encouraged so as to maximize the benefits.

6.4.5.2 Impact of irrigation on malaria transmission

Inspite of the disparity in vector numbers, malaria was as prevalent, or even more prevalent, in the irrigation scheme than in the swamp area. In two of three malaria surveys among school children, Perkerra Primary School, on the irrigation scheme, had higher percentages of infection

than Kapkuikui Primary School near the swamp (Table 21). One of these differences (October) was highly significant (X^2=12.61, p< 0.001). During these surveys, all the 7 cases of gametocyte presence in the blood, were recorded in Perkerra. Also, 62% (16/26) of heavy infection cases were recorded in Perkerra. as against 35% (9/26) at Kapkuikui. These are strong indications of a higher degree of transmission at Perkerra than at Loboi.

The explanation for this apparent contradiction of fewer mosquitoes causing more malaria, was found in the analyses of some of the epidemiological factors involved in malaria transmission. The three most important factors are the sporozoite rate, the biting rate and the survival rate of the vector (Macdonald, 1952 a; Bruce-Chwatt, 1985). The mean sporozoite rate for A.gambiae at Perkerra was higher than that at Loboi. On the other hand, the mean bites per person per night was higher at Loboi, as a result of higher mosquito densities, than at Perkerra (Table 19). These two differences which were not significant statistically seemed to have cancelled out each other, making the mean inoculation rate (biting rate x sporozoite rate) in the two locations approximately equal (0.048 and 0.053 for Loboi and Perkerra respectively). The mean survival rate of A.gambiae at Perkerra (0.87) was, however, significantly higher than at Loboi (o.81), (X^2=6.7, p< 0.01).

The most important factor in the determination of malaria transmission in any locality is the mean life expectancy of infective vector, (Macdonald, 1952 a; Bruce-

Chwatt, 1985). It is a function of the daily survival rate and the duration of the extrinsic or sporogonic period of development. The extrinsic period of development is the time (in days) it takes the malaria parasite to develop inside the mosquito and, for Plasmodium falciparum, is about 12 days at 26°C (Macdonald, 1952 ; Bruce-Chwatt, 1985). The higher daily survival rates of A.gambiae at Perkerra than at Loboi therefore means that the mosquitoes lived longer at Perkerra. This period was adequate for the completion of development of the malaria parasites than at Loboi. It also implies that female A.gambiae mosquitoes could give approximately the same numbers of infective bites/person/night (as determined by the mean inoculation rates) over a significantly longer period at Perkerra than at Loboi. This was responsible for the higher infection rates at Perkerra despite the lower mosquito density.

The mean inoculation rate of A.gambiae was four times higher than that of A.funestus at Loboi where both species occurred in approximately equal numbers (0.053:0.0133, Table 19). The role of A.funestus in malaria transmission was evedently negligible when compared with A.gambiae. Despite its higher numbers at Loboi than at Perkerra, infection was still higher at the latter location. Its importance lies probably in helping to maintain transmission during the period of low A.gambiae numbers.

The higher survival rates of adult A.gambiae at Perkerra is probably due to the greater shade provided by crops,

especially those such as pepper and bananas which continue to grow long after the rains have stopped. There have also been massive tree planting by the settlers and the Forestry department in the scheme area. In addition, the numerous animal burrows along the edges of the irrigation canals create micro-climates conducive to mosquito survival. Excluding the swamp, Loboi is drier and more sparsely forested except during the farming season, which coincides with the rains.

CHAPTER 7

SUMMARY

1. A comparative study of the ecology of mosquito vectors of malaria was undertaken in the Perkerra irrigation scheme and the Loboi swamp in Marigat division of Baringo district, Kenya.

2. The species diversity and seasonal population fluctuations were studied in relation to the following climatic factors: Rainfall, Temperature, Relative Humidity and Windspeed.

3. Seventeen mosquito species were collected and identified in the area during the study. Seven were Anophelini and ten were Culicini. All 17 species were breeding in the Loboi swamp while only 5 species were found at the Perkerra irrigation scheme.

4. Two of the species, Anopheles gambiae s.l. and A.funestus are known malaria vectors in Kenya. A third species, A.pharoensis, is a vector in some parts of the world but not in Kenya. The detailed ecological studies focussed on these 3 species.

5. Anopheles gambiae and A.funestus breed all y ar round in Loboi and were the most abundant species there. A.gambiae

reached its peak population at the height of the rainy season, April - June. A.funestus peaked towards the end of the cool dry period, August - November. A.pharoensis was collected in May - December only, with a peak in July.

6. At Perkerra, A.gambiae was the most abundant species and was found all year round, with the peak population in September, three months after the rains. A.funestus was very scanty while A.pharoensis was absent.

7. Rainfall was the most important factor regulating A.gambiae numbers at Loboi and there was a highly significant correlation between numbers and rainfall ($p < 0.01$, by Anova).

8. At Perkerra there was no correlation between rainfall and A.gambiae numbers. Irrigation practices rather than climatic factors were the major factors regulating mosquito diversty and abundance.

9. Intermittent irrigation, by limiting the amount and duration of water suitable for mosquito breeding, reduced their numbers in Perkerra. Constant weeding of the irrigation canals rendered them unsuitable for species such as A.funestus and A.pharoensis which require vegetational cover in their breeding sites.

10 Stage-specific and age-specific survivorship of the immature stages of Anopheles gambiae were studied using vertical life table methods. Adult survival rates and age composition were estimated from parous ratios based on ovarian dissections.

11 Survivorship during the rainy season, from first instar to emergence was 0.085(91.5% mortality) at both Loboi and Perkerra. It dropped to zero (measured only at Loboi) in the dry, season.

12 Mortality factors were not analysed but known predators of mosquito pre-imagines found in the breeding sites were collected and counted. The great diversity and large numbers of these predators collected suggested that predation was an important mortality factor. No evidence of larval infection with Coelomomyces or any other pathogen was found.

13 There was a seasonal variation in the age composition of adult female A.gambiae both within and between habitats. The parous rates were lowest in the dry season, February-March and highest in the cool dry period following the rains, July-September. In both habitats there was a significant difference between the lowest and highest parous rates ($p<0.01$). Mean parous rates were significantly higher at Perkerra than at Loboi ($p<0.01$).

14 Daily survival rates were significantly higher at Perkerra than at Loboi ($p<0.001$). The relationship between mortality and age was not investigated but the parous and daily survival rates obtained were high enough to suggest that many females lived up to the age at which most malaria transmission occured (5 - 7 oviposition cycles).

15 The higher survival rates at Perkerra is thought to be due to factors related to irrigation, chief among which is the provision of cooler and more humid micro-climate by growing crops and shade trees,

16 Vector behaviour was studied with respect to biting activity, resting habits and host preferences in the three major anopheline species.

17 The pattern of biting activities indoors and outdoors in each of the three species were similar, suggesting that the indoor and outdoor biting populations were homogeneous.

18 Biting activity for Anopheles gambiae and funestus was higher indoors than outdoors while it was the converse for A.pharoensis. Peak biting activity for A.gambiae and A. funestus occurred at 2300-0100 hours and 0100-0300 hours respectively while in A. pharoensis the peak was at 2100-2300 hours.

19. A.gambiae and A.funestus were essentially endophilic, that is, house-haunting in their resting habits. However, the ratio of freshly fed to gravid in indoor resting A.gambiae was significantly higher ($p < 0.001$), indicating that there was a considerable degree of exophily among the gravid females. This incipient exophily was also noticeble in A.funestus gravid females but to a lesser degree than in gambiae.

20. Anopheles pharoensis was strongly exophilic, with up to 79% of the females leaving the house after feeding to seek outdoor resting sites.

21. Anopheles gambiae was strongly anthropophilic, and fed predominantly on human blood, A.funestus was moderately so while A.pharoensis preferred feeding on bovine blood. The respective human bloodindices (HBI) for the three were 88.6%, 58.8% and 35.7%.

22. Malariometric studies established the prevalence and seasonality of malaria transmission and the relative importance of the two main anopheline species as vectors.

23. Calculations of the crude inoculation rates showed that malaria transmission was highest April - July and lowest December - February at Loboi, whereas at Perkerra, transmission was highest July - September and lowest December - February.

24. Malaria infection rates among school-age children was highest at Loboi in July (16.9%) and at Perkerra in October (26.9%). The 5-9 year olds were most susceptible to malaria followed by the 10-14 year olds. In infants the highest infection rates were in the 12-22 month olds.

25. Malaria prevalence rates were similar in the two locations in March and July but were significantly higher at Perkerra than at Loboi in October ($p < 0.001$). Since mean crude inoculation rates were equal in the two locations (0.05) the difference in prevalence rates was probably attributable to the higher survival rates of A.gambiae at Perkerra.

26. The mean crude inoculation rate of A.gambiae was four times higher than that of A.funestus (0.053: 0.013); the former is a more efficient vector than the latter. Thus, although A.funestus was present in equal numbers as A.gambiae at Loboi but was almost totally absent at Perkerra, malaria prevalence was slightly higher in the latter location. This shows that the role of A.funestus in malaria transmission was very negligible and that A.gambiae was the main vector

27. In comparing the overall contributions of the Perkerra irrigation scheme and the Loboi swamp to mosquito breeding and malaria transmission, it is concluded that the Perkerra irrigation scheme does not promote mosquito breeding to the same extent that is found in many other irrigation schemes. It is therefore strongly suggested that those beneficial

irrigation practices such as intermittent flooding, responsible for reduced breeding and malaria transmission should be positively encouraged.

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APPENDIX 1. MONTHLY TOTALS OF THE MAJOR MOSQUITO SPECIES COLLECTED INDOORS AT THE 4 LOCATIONS SAMPLED FROM JANUARY TO DECEMBER, 1986.

1A: Anopheles gambiae s.l.

MOMTHS	KAPKUIKUI, LOBOI			TINGITINYON			Rl, PERKERRA			ENDAU VILLAGE		
	Male	Female	Total	Male	Fem.	Total	Male	Female	Total	Male	Female	Total
JANUARY	21	19	40	3	27	30	1	3	4	-	-	-
FEBRUARY	1	28	29	12	66	78	1	4	5	-	-	-
MARCH	10	77	87	46	82	128	1	8	9	0	0	0
APRIL	20	91	111	25	119	144	2	11	13	0	0	0
MAY	85	461	546	23	150	173	0	14	14	1	26	27
JUNE	14	122	136	39	153	192	3	35	38	1	33	34
JULY	10	147	157	22	127	149	7	89	96	2	133	155
AUGUST	39	104	143	40	89	129	5	198	203	0	29	29
SEPTEMBER	11	71	82	15	43	58	32	223	255	9	49	58
OCTOBER	3	60	58	38	138	176	19	118	137	0	2	2
NOVEMBER	0	35	35	84	112	196	3	36	37	0	4	4
DECEMBER	4	53	57	39	84	123	7	25	32	0	1	0
TOTALS	218	1248	1471	386	1190	1576	81	764	845	13	257	270

APPENDIX 1. MONTHLY TOTALS OF THE MAJOR MOSQUITO SPECIES COLLECTED INDOORS AT THE 4 LOCATIONS SAMPLED FROM JANUARY TO DECEMBER, 1985.

1B: Anopheles funestus.

MONTHS	KAPKUIKUI, LOBOI			TINGTTINYON			Rl, PERKERRA			ENDAU VILLAGE		
	Male	Female	Total	Male	Fem.	Total	Male	Female	Total	Male	Female	Total
JANUARY	0	4	4	1	10	11	0	0	0	-	-	-
FEBRUARY	0	14	14	0	18	18	0	3	3	-	-	-
MARCH	4	38	42	23	52	74	0	3	3	0	0	0
APRIL	10	73	83	8	46	54	0	0	0	0	0	0
MAY	0	40	40	0	41	41	0	0	0	0	0	0
JUNE	2	41	43	6	37	43	0	0	0	0	0	0
JULY	3	30	33	6	29	35	0	0	0	0	0	0
AUGUST	39	145	184	28	69	97	0	5	5	0	0	0
SEPTEMBER	25	79	104	1	22	23	1	8	9	0	1	1
OCTOBER	51	179	230	90	201	291	4	4	8	0	0	0
NOVEMBER	89	472	561	31	39	70	0	0	0	0	0	0
DECEMBER	17	120	137	93	153	246	0	0	0	0	0	0
TOTALS	240	1235	1475	287	717	1004	5	23	28	0	1	

APPENDIX 1. MONTHLY TOTALS OF THE MAJOR MOSQUITO SPECIES COLLECTED INDOORS AT THE 4 LOCATIONS SAMPLED FROM JANUARY TO DECEMBER, 1986.

1C: Culicines.

MONTHS	KAPKUIKUI, LOBOI			TINGTTINYON			RI, PERKERRA			ENDAU VILLAGE		
	Male	Female	Total	Male	Fem.	Total	Male	Female	Total	Male	Female	Total
JANUARY	5	11	16	17	55	72	0	0	0	-	-	-
FEBRUARY	13	39	52	47	136	183	0	2	2	-	-	-
MARCH	4	45	49	50	243	296	2	5	5	7	1	5
APRIL	13	37	50	58	199	257	10	13	23	11	27	38
MAY	19	33	52	5	18	23	2	5	7	0	0	0
JUNE	1	12	13	2	14	16	0	3	3	0	0	0
JULY	0	1	1	0	1	1	0	0	0	0	1	1
AUGUST	3	27	30	0	7	7	0	0	0	0	0	0
SEPTEMBER	0	26	26	4	4	2	6	0	0	0	1	1
OCTOBER	12	45	57	11	40	51	3	3	6	0	2	2
NOVEMBER	44	130	174	7	17	24	1	3	4	0	0	0
DECEMBER	20	60	80	7	14	21	3	9	12	0	0	0
TOTALS	143	495	600	208	746	954	21	41	64	12	36	48

APPENDIX 2 A

RESULTS OF PARASITE SURVEY IN SCHOOLS.

Province..RIFT VALLEY..

District..BARINGO.....

Locality..LOBOI PRIMARY SCHOOL..

Date...9TH MARCH 1987..

	0-11m	12-23m	2-4	5-9	10-14	15-19	20+	Overall	s.i.r.	Pa For	5 - 9 Only
Exam	-	-	-	51	91	80	4	226			51
pos.	-	-	-	4	3	1	0	8			4
i.p.r	-	-	-	-	-	-	-	-			
p.r	-	-	-	7.8%	3.3%	1.3%	-	3.5%			7.8%
f.g	-	-	-	-	-	-	-	-			
g.r	-	-	-	-	-	-	-	-			
Mx	-	-	-	-	-	-	-	-			
Hi	-	-	-	-	-	-	-	-			
%Hi	-	-	-	-	-	-	-	-			
p.f	-	-	-	4	3	1	0	8	3.5%	100%	
p.m	-	-	-	-	-	-	-	-	0%	0%	
p.o	-	-	-	-	-	-	-	-	0%	0%	
p.v	-	-	-	-	-	-	-	-	0%	0%	

NOTES:

pos. = positives.
i.p.r = infant parasite rate
p.r = parasite rate
f.g = falciparum gametocyte
g.r = gametocyte rate
Mx = mixed infections
Hi = heavy infections
p.f = Plasmodium falciparum
p.m = Plasmodium malariae
p.o = Plasmodium ovale
p.v = Plasmodium vivax
s.i.r = species infection rate
Pa.for = Parasite formula

APPENDIX 3 9

RESULTS OF PARASITE SURVEY IN SCHOOLS.

Province .RIFT VALLEY..

District..BARINGO.....

Locality..KAPKUTWI PRIMARY SCHOOL..

Date...19TH MARCH 1987..

	0-11m	12-23m	2-4	5-9	10-14	15-19	20+	Overall	s.i.r.	s.f.r	5 - 9 only
Exam	-	-	-	39	40	7	10	96			39
pos.	-	-	-	5	7	0	3	11			6
i.p.r	-	-	-	-	-	-	-				
p.r	-	-	-	15.4%	5 0%	-	4/8	11.5%			15.4%
f.g	-	-	-					-			
g.r	-	-	-	-	-	-	-				
Mx	-	-	-	-	-	-	-	-			
Hi	-	-	-	-	-	-	-	-			
%Hi	-	-	-	-	-	-	-	-			
p.f	-	-	-	6	2	0	3	11	11.5%	100%	
p.m	-	-	-	-	-	-	-	-	0%	0%	
p.o	-	-	-	-	-	-	-	-	0%	0%	
p.v	-	-	-	-	-	-	-	-	0%	0%	

NOTES:

pos. = positives.
i.p.r = infant parasite rate
p.r = parasite rate
f.g = falciparum gametocyte
g.r = gametocyte rate
Mx = mixed infections
Hi = heavy infections
p.f = Plasmodium falciparum
p.m = Plasmodium malariae
p.o = Plasmodium ovale
p.v = Plasmodium vivax
s.i.r = species infection rate
Pa.for = Parasite formula

APPENDIX 2 C

RESULTS OF PARASITE SURVEY IN SCHOOLS.

Province..RIFT VALLEY..

District..BARINGO.....

Locality..PERKERRA PRIMARY SCHOOL..

Date...19TH MARCH 1987..

	0-11m	12-23m	2-4	5-9	10-14	15-19	20+	Overall s.i.r.	Pa For	5 - 9 Only
Exam	-	-	-	79	179	66	0	324		79
pos.	-	-	-	19	28	2	-	49		19
i.p.r	-	-	-	-	-	-	-	-		
p.r	-	-	-	20.1%	15.6%	-	3.0%	15.1%		24.1%
f.g	-	-	-	4	1	-	-	5		4
g.r	-	-	-	21.1%	3.6%	-	-	10.2%		8.2%
Mx	-	-	-	-	-	-	-	-		
Hi	-	-	-	1	1	-	-	2		1
%Hi	-	-	-	2.0%	2.0%	-	-	4.1%		2.0%
p.f	-	-	-	19	28	2	0	49	15.1%	100%
p.m	-	-	-	-	-	-	-	-	0%	0%
p.o	-	-	-	-	-	-	-	-	0%	0%
p.v	-	-	-	-	-	-	-	-	0%	0%

NOTES:

pos. = positives.
i.p.r = infant parasite rate
p.r = parasite rate
f.g = falciparum gametocyte
g.r = gametocyte rate
Mx = mixed infections
Hi = heavy infections
p.f = Plasmodium falciparum
p.m = Plasmodium malariae
p.o = Plasmodium ovale
p.v = Plasmodium vivax
s.i.r = species infection rate
Pa.for = Parasite formula

APPENDIX 2 D

RESULTS OF PARASITE SURVEY IN SCHOOLS.

Province..RIFT VALLEY..

District..BARINGO.....

Locality..LOSOI PRIMARY SCHOOL..

Date...17TH JULY 1987.

	0-11m	12-23m	2-4	5-9	10-14	15-19	20+	Overall s.i.r.	Pa.For		5 - 9 Only
Exam	-	-	-	32	101	70	4	207			32
pos.		-	-	2	6	2	0	10			2
i.p.r	-	-	-	-	-	-	-	-			
p.r	-	-	-	6.3%	5.9%	-	2.9%	4.8%			6.3%
f.g	-	-	-	-	-	-	-	-			
g.r	-	-	-	-	-	-	-	-			
MX	-	-	-	-	-	-	-	-			
HI	-	-	-	-	1	-	-	1			1
%HI	-	-	-	-	17%	-	-	10.0%			10%
p.f	-	-	-	2	6	2	0	10	4.8%	100%	
p.m	-	-	-	-	-	-	-	-	0%	0%	
p.o	-	-	-	-	-	-	-	-	0%	0%	
p.v	-	-	-	-	-	-	-	-	0%	0%	

NOTES:

pos. = positives.
i.p.r = infant parasite rate
p.r = parasite rate
f.g = falciparum gametocyte
g.r = gametocyte rate
MX = mixed infections
HI = heavy infections
p.f = Plasmodium falciparum
p.m = Plasmodium malariae
p.o = Plasmodium ovale
p.v = Plasmodium vivax
s.i.r = species infection rate
Pa.for = Parasite formula

APPENDIX 2 E

RESULTS OF PARASITE SURVEY IN SCHOOLS.

Province..RIFT VALLEY..

District..BARINGO.....

Locality..KAPKUIKUI PRIMARY SCHOOL..

Date...17TH JULY 1987..

	0-11m	12-23m	2-4	5-9	10-14	15-19	20+	Overall	s.i.r.	Pa.for	5 - 9 Only
Exam	-	-	-	49	24	9	7	89			49
pos.	-	-	-	8	6	1	0	15			8
i.p.r	-	-	-	-	-	-	-	-			
p.r	-	-	-	16.3%	25.0%	11.1%	0%	16.9%			16.3%
f.g	-	-	-	-	-	-	-	-			
g.r	-	-	-	-	-	-	-	-			
Mx	-	-	-	-			-	-			
Hi	-	-	-	5	3	1	-	9			5
%Hi	-	-	-	33.3%	20%	6.7%	-	60.0%			33.3%
p.f	-	-	-	8	6	1	0	15	16.9%	100%	
p.m	-	-	-	-	-	-	-	-	0%	0%	
p.o	-	-	-	-	-	-	-	-	0%	0%	
p.v	-	-	-	-	-	-	-	-	0%	0%	

NOTES:

pos. = positives.
i.p.r = infant parasite rate
p.r = parasite rate
f.g = falciparum gametocyte
g.r = gametocyte rate
Mx = mixed infections
Hi = heavy infections
p.f = Plasmodium falciparum
p.m = Plasmodium malariae
p.o = Plasmodium ovale
p.v = Plasmodium vivax
s.i.r = species infection rate
Pa.for = Parasite formula

APPENDIX 2 I

RESULTS OF PARASITE SURVEY IN SCHOOLS.

Province..RIFT VALLEY..

District..BARINGO.... ..

Locality..PERKERRA PRIMARY SCHOOL..

Date...17th JULY 1987..

	0-11m	12-23m	2-4	5-9	10-14	15-19	20+	Overall	s.i.r.	Pa For	5 - 9 Only
Exam	-	-	-	92	172	78	?	342			92
pos.	-	-	-	17	23	6	0	46			17
i.p.r	-	-	-	-	-	-	-	-			
p.r	-	-	-	18.5%	13.4%	7.7%	0%	13.5%			18.5%
f.g	-	-	-	2	-	-	-	2			
g.r	-	-	-	0.6%	-	-	-	0.6%			
Mx	-	-	-	-	-	-	-	-			
Hi	-	-	-	6	7	1	-	14			6
%Hi	-	-	-	33.3%	20%	6.7%	-	60.0%			13.0%
p.f	-	-	-	17	23	6	0	46	13.5%	100%	
p.m	-	-	-	-	-	-	-	-	0%	0%	
p.o	-	-	-	-	-	-	-	-	0%	0%	
p.v	-	-	-	-	-	-	-	-	0%	0%	

NOTES:

pos. = positives.
i.p.r = infant parasite rate
p.r = parasite rate
f.g = falciparum gametocyte
g.r = gametocyte rate
Mx = mixed infections
Hi = heavy infections
p.f = Plasmodium falciparum
p.m = Plasmodium malariae
p.o = Plasmodium ovale
p.v = Plasmodium vivax
s.i.r = species infection rate
Pa.for = Parasite formula

APPENDIX 2 G

RESULTS OF PARASITE SURVEY IN SCHOOLS.

Province..RIFT VALLEY..

District..BARINGO.....

Locality..KAPKUIKUI PRIMARY SCHOOL..

Date...23 OCTOBER 1987..

	0-11m	12-23m	2-4	5-9	10-14	15-19	20+	Overall s.i.r.	Pa For		2 - 9 Only
Exam	5	10	18	50	40	5	0	128			68
pos.	2	2	3	3	2	0	-	12			6
i.p.r	40,0%	-	-	-	-	-	-	-			8.8%
p.r	-	20.0%	16.7%		6.0%	5.0%	0%	9.4%			
f.g	-	-	-		-	-	-	-			
g.r	-	-	-	-	-	-	-	-			
Mx	-	-	-	-	-	-	-	-			
Hi	-	-	-	-	-	1	-	1			1
%Hi	-	-	-	-	8.3%		-	8.3%			8.3%
p.f	2	2	3	3	2	-	-	12	9.4%	100%	
p.m	-	-	-	-	-	-	-	-	0%	0%	
p.o	-	-	-	-	-	-	-	-	0%	0%	
p.v	-	-	-	-	-	-	-	-	0%	0%	

NOTES:

pos. = positives.
i.p.r = infant parasite rate
p.r = parasite rate
f.g = falciparum gametocyte
g.r = gametocyte rate
Mx = mixed infections
Hi = heavy infections
p.f = Plasmodium falciparum
p.m = Plasmodium malariae
p.o = Plasmodium ovale
p.v = Plasmodium vivax
s.i.r = species infection rate
Pa.for = Parasite formula

APPENDIX 2 H

RESULTS OF PARASITE SURVEY IN SCHOOLS

Province..RIFT VALLEY..

District..BARINGO.....

Locality..PERKERRA PRIMARY SCHOOL..

Date...23 OCTOBER 1987..

	0-11m	12-23m	2-4	5-9	10-14	15-19	20+	Overall s.i.r.	Pa For		2 - 9 Only
Exam	9	17	34	63	12	10	0	145			97
pos.	3	7	9	18	2	0	-	39			27
i.p.r	33.3%	-	-	-	-	-	-	-			27.8%
p.r	-	41.2%	27%	28.6%	16.7%	-	0%	26.9%			
f.g	-	-	-	-	-	-	-	-			
g.r	-	-	-	-	-	-	-	-			
Mx	-	-	-	-	-	-	-	-			
Hi	-	-	-	2	-	-	-	2			2
%Hi	-	-	-	-	5.1%	-	-	5.1%			5.1%
p.f	3	7	9	18	2	0	-	39	26.9%	100%	
p.m	-	-	-	-	-	2	-	-	0%	0%	
p.o	-	-	-	-	-	-	-	-	0%	0%	
p.v	-	-	-	-	-	-	-	-	0%	0%	

NOTES:

pos. = positives.
i.p.r = infant parasite rate
p.r = parasite rate
f.g = falciparum gametocyte
g.r = gametocyte rate
Mx = mixed infections
Hi = heavy infections
p.f = Plasmodium falciparum
p.m = Plasmodium malariae
p.o = Plasmodium ovale
p.v = Plasmodium vivax
s.i.r = species infection rate
Pa.for = Parasite formula

APPENDIX 3

Records of Meteorological Data from the Perkerra Agricultural Research Station, Marigat, September 1985 to December 1987.

A:

1985

MONTH	WINDSPEED (m.p.h.)	TEMPERATURE(°C) MAX.	MIN.	REL. HUMIDITY(%) A.M	P.M	RAINFALL(mm) AMOUNT	DAYS
SEPT.	48.47	33.8	16.2	55.4	32.0	24.2	6
OCT.	75.19	34.3	17.6	50.8	34.1	9.5	7
NOV.	60.63	32.1	17.5	53.2	37.9	32.4	8
DEC.	64.20	33.6	17.3	51.6	32.6	1.8	2

APPENDIX 3. (Contd.)

Records of Meteorolcgical Data from the Perkerra Agricultural Research Station, Marigat, September 1985 to December 1987.

B:

1986.

MONTH	WINDSPEED (m.p.h.)	TEMPERATURE(°C) MAX.	MIN.	REL. HUMIDITY(%) A.M	P.M	RAINFALL(mm) AMOUNT	DAYS
JAN.	66.32	34.8	17.1	45.9	28.8	0	0
FEB.	71.95	35.0	18.4	44.5	31.4	0	0
MAR.	69.67	35.1	18.4	53.6	30.8	16.7	3
APR.	51.56	33.3	18.9	72.2	48.9	163.5	20
MAY	42.54	31.5	18.0	71.1	46.5	50.7	18
JUN.	30.06	30.2	17.6	83.9	51.0	103.9	15
JUL.	23.90	30.6	16.6	73.9	49.0	43.1	9
AUG.	35.32	31.6	15.1	62.0	41.1	42.7	7
SEP.	50.32	32.1	15.6	58.5	34.3	50.3	5
OCT.	68.71	32.6	17.2	58.1	35.7	6.5	2
NOV.	59.19	33.3	18.4	59.4	45.8	22.4	2
DEC.	54.19	36.5	17.7	68.0	55.0	10.9	2
TOTAL	-	-	-	-	-	510.7	83
MEAN	59.81	33.05	17.4	62.6	41.5	42.6	6.9

APPENDIX 3. (Contd.)

Records of Meteorological Data from the Perkerra Agricultural Research Station, Marigat, September 1985 to December 1987.

C:

1987

MONTH	WINDSPEED m.p.h.)	TEMPERATURE(°C) MAX.	MIN.	REL. HUMIDITY(%) A.M	P.M	RAINFALL(mm) AMOUNT	DAYS
JAN.	64.39	34.1	18.7	61.5	44.0	26.0	2
FEB	71.89	34.0	17.2	63.3	36.3	64.2	3
MAR.	67.37	35.0	18.7	70.3	48.5	19.7	7
APR.	49.65	31.3	19.5	69.6	45.9	133.5	11
MAY	31.60	34.5	16.6	76.8	50.4	101.3	18
JUN.	23.80	29.6	18.0	74.7	49.2	127.3	12
JUL.	41.72	32.7	16.5	63.0	38.8	12.5	6
AUG.	53.38	34.0	16.9	60.6	38.1	31.5	10
SEP.	62.19	35.8	17.2	50.1	29.9	3.7	2
OCT.	66.53	36.3	19.1	46.4	29.5	7.4	3
NOV.	53.06	32.8	19.1	59.1	39.3	79.4	16
DEC.	58.75	35.6	17.3	54.4	37.0	0.60	1
TOTAL	-	-	-	-	-	506.9	89
MEAN	55.10	33.8	17.9	62.5	40.6	42.2	7.4