ECOLOGICAL AND BEHAVIOURAL STUDIES OF MOSQUITOES IN MWEA TEBERE IRRIGATION SCHEME, KIRINYAGA DISTRICT, KENYA, WITH SPECIAL REFERENCE TO *ANOPHELES ARABIENSIS* (DIPTERA:CULICIDAE)

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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CERTIFICATION

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ABSTRACT

During this investigation which took place between April 1989 and February 1991, an attempt was made to determine the impact of rice irrigation practices on 1) mosquito species diversity and their relative population density; 2) malaria infection rates in both the human and mosquito populations. The studies also investigated the relative importance and attractiveness of various hosts for different mosquito species.

Mosquitoes were sampled from two study villages, Mbui Njeru and Mathangauta which are located in the Mwea Irrigation scheme. The two villages were selected mainly because their positions relative to irrigated areas offered a good contrast for comparative studies on mosquitoes and their hosts. Mbui Njeru lies in the centre of the irrigation scheme and is thus surrounded by paddies from all sides. Mathangauta on the other hand lies at the periphery and is encroached by irrigated paddies on only one side. The two villages are also accessible throughout the year.

Mosquito sampling was carried out in each of the four houses in each village. Sampling was replicated daily for seven days each month in every village. Sampling methods for adult mosquitoes included collections from daytime indoor and outdoor resting sites using battery powered aspirators and pyrethrum knock-down spray. Mosquitoes entering houses for feeding or resting purposes were also collected using miniature light traps. Larvae were collected from flooded rice paddies and pools of stagnant water using standardized dipping methods. Mosquitoes collected by the various

paddies the relative numbers of *An. arabiensis* decreased.

In Mathangauta village the two vector species alternated in their predominance. When the numbers of *An. arabiensis* was high that of *An. funestus* declined and vice versa. The increase in *An. arabiensis* coincided with the preparation of nurseries and seedling transplantation while the increase in *An. funestus* coincided with the draining of water from the paddies and harvesting. Irrigation water released from paddies during harvesting found its way into drainage canals with dense submerged vegetation, thus forming suitable breeding sites for *An. funestus*.

Variation in the numbers of *An. arabiensis* in Mbui Njeru was influenced by seasonal rainfall pattern in addition to rice cultivation cycle. Mosquito numbers were low during the rainy season, probably due to wash off effects of breeding sites by the rain water, but increased during the dry season. The mean counts between the two vector species *An. arabiensis* and *An. funestus* were also significantly different with the former being the most abundant and present throughout the year. The species from both indoor and outdoor sites were also significantly different with more mosquitoes recorded indoors than outdoors. Suprisingly, it was also noted that the incidence of malaria was high when the relative numbers of *An. arabiensis* was low compared to the other months. It is therefore likely that the main vector responsible for transmission of malaria in Mwea Tebere is *An. funestus*.

Investigations on the sporozoite rates of dissected female mosquito vectors showed that the monthly average sporozoite rate

was not significantly different between the two villages (X^2 = 0.303; P>0.05). The difference in the sporozoite rate with respect to the seasons was also not significant (X^2 = 2.25; P>0.05). All the mosquitoes (n = 4594) tested for sporozoite rate using the Enzyme-linked Immunosorbent Assay (ELISA) were negative. This confirmed earlier observations of low sporozoite rates through dissections of salivary glands.

Studies on resting behaviour of female *Anopheles arabiensis* and *Anopheles funestus* showed that freshly fed mosquitoes preferred to rest indoors. A comparison of the resting behaviour of *An. arabiensis* and *An. rufipes* showed that fed females of the latter rested predominantly outdoors. Results on feeding behaviour determined through blood meal analysis showed that *An. arabiensis* fed predominantly on bovine hosts (79%). The difference in the numbers feeding on human and bovine hosts was significant (P< 0.05) with more *An. arabiensis* feeding on bovine hosts.

Malaria parasite prevalence rate in the human population for Mbui Njeru and Mathangauta was less than 8.7% for all age and sex groups. *Plasmodium falciparum* was the predominant species comprising 100% of the infections recorded. The malaria prevalence rate for Mbui Njeru was higher than that of Mathangauta village ($F_{1,1}$ = 12.63; P<0.01) and all the other villages screened during the second year of this study. The peak malaria prevalence rate occurred in the month of July for both Mbui Njeru and Mathangauta villages. It was noted that the infection rate was higher in males (6.3%) than in females (3.7%) ($F_{1,1}$ = 6.27; P<0.01). There was also

significant difference in the malaria infection rate among the various age-groups. The age-group with the highest infection rate was the 10-14 year olds.

The overall outcome of this study was that the numbers of mosquitoes were enough to maintain malaria transmission throughout the year in the area studied. However, the parasite infection rate in both vector and human population was lower than would be expected in the presence of such high numbers of vector mosquitoes. This situation was possibly due to the fact that the vector species were predominantly feeding on bovine hosts than on human hosts. The tendency by mosquitoes to feed more on animals than human beings is referred to as zoophily. Such feeding behaviour may form the basis of zooprophylaxis, an important method through which man-vector contact could be minimised. Zooprophylaxis is a practical malaria control method in which the community can participate by being encouraged to keep at least a few cows outside their houses. However, there is need for further studies to determine the optimal densities, directions and distances at which such barrier animals could be deployed, to ensure that they on the other hand do not worsen the situation by attracting large numbers of potential vectors to human habitations.

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CHAPTER 1

1. GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 BACKGROUND INFORMATION

Mosquitoes are the most important single group of insects with regard to Public Health (Bruce-Chwatt, 1985; Service, 1989c). They belong to the order Diptera, family Culicidae. The family is further sub-divided into three sub-families namely Anophelinae, Culicinae and Toxorhynchitinae (Gillies and De Meillon, 1968). Members of the family Culicidae are well known due to their ability to transmit organisms that cause diseases such as malaria, yellow fever, dengue fever, filariasis and most of the arthropod-borne viral types of encephalitis (Muirhead-Thompson 1951; Hocking, 1971; Taylor et al, 1990). Mosquitoes are a remarkably adaptable and fully cosmopolitan group of insects with over 3,000 species distributed throughout the world (Service, 1976).

Out of the several diseases transmitted by mosquitoes, malaria is the most important. The disease is caused by protozoan parasite of the genus *Plasmodium*. It is transmitted through the bite of a female *Anopheles* mosquito. The resulting disease causes a lot of suffering to the individuals and the community. The disease is incapacitating and results in low economic productivity. Malaria is endemic in 102 countries in the world and is responsible for over 100 million clinical cases and two million deaths each year. In Africa 90 million clinical cases are estimated to occur annually while some 260 million people are considered as parasite carriers (WHO, 1992).

Among other disease organisms transmitted by mosquitoes are

Wuchereria bancrofti transmitted by *Anopheles gambiae* and *Culex quinquefasciatus* which causes bancroftian filariasis and several arboviruses which include yellow fever and dengue fever.

In an authoritative review by Bruce-Chwatt (1985) it is recalled that the link in the transmission of disease organisms by arthropods was first realised after evidence in China showed that mosquitoes acted as hosts of human filarial parasites and that in Africa, tsetse flies could transmit trypanosome from one animal to another. This led to the suspicion that mosquitoes could be the possible vectors of malaria (Hocking, 1971). Ross (1897) showed a link in the role of mosquitoes in the transmission cycle of malaria. This discovery stimulated further work by several scientists on the biology of the insect (Boyd, 1949) and the parasite and their development in both man and mosquitoes. Experiments by Manson (1900) confirmed that female *Anopheles* mosquitoes transmitted malaria parasite *Plasmodium*.

The main factors that determine the efficiency of vector species include, abundance and preference of certain hosts. For instance, an important vector of human disease must be relatively abundant and its habitat adjacent to human settlement. On the other hand feeding preference is important in the epidemiology of disease transmission since mosquitoes show considerable variation in their host preferences (Nishimura, 1982). Some species such as *An. rufipes* feed predominantly on cattle, horses or other domestic animals, while others like *An. gambiae s.s.* prefer to feed mainly on man. Behavioural terms respectively used to differentiate feeding preference on animals and man are zoophily and

anthropophily. An efficient vector usually has a narrow host range. Other categories of feeding behaviour include: Species that feed almost entirely on mammals; those that feed on birds and those that readily feed on both classes of animals (Tempelis and Reeves, 1964). In this latter categorizations anophelines fit into the first group, although exceptional behaviour is sometimes reported. For example, *Anopheles letifer* in Malaya shows strong attraction to chicken and ducks (Moorhouse and Wharton, 1965); also the bromeliad-breeding *Anopheles cruzi* in Brazil has been described as an avian feeder (Forattini *et al.*, 1968). Feeding behaviour is important in that a vector of a particular disease organism would loose parasites when it feeds on a non host.

Resting places for mosquitoes are important as they allow time for blood digestion, leading to subsequent maturation of ovaries. Factors which affect the choice of mosquito resting places include temperature, humidity, protection against sunlight, wind and predators. Behavioural terms used to differentiate resting places for mosquitoes are endophily and exophily. The former term refers to those species that prefer to rest indoors while the latter defines species that rest outdoors for most of the gonotrophic cycle. Resting behaviour is especially important when considering control measures particularly those involving the use of residual insecticides indoors.

Under natural conditions, female mosquitoes remain alive for 2-3 weeks (Service, 1976). Longevity in female mosquitoes is important because an efficient vector must live long enough to enable the malaria parasite undergo complete development, thus

enhance malaria transmission. Longevity of female mosquitoes is usually determined by observing the condition of the ovaries. In so doing, mosquitoes can be grouped as nulliparous or parous depending on whether or not they have completed an oviposition cycle. Nulliparous females are not old enough to transmit malaria because sporozoite development requires 10-12 days to be complete while an oviposition cycle lasts for only 2-3 days. For epidemiologic purposes, the impact of mosquito control by use of residual insecticides can be measured by determining parous rate of the vector population.

Thirty two species of Anopheles mosquitoes have been reported to occur in Kenya. Of these, *Anopheles funestus* Giles, and *Anopheles gambiae* Giles (1902) species complex (Gillies and De Meillon, 1968) are confirmed vectors of disease organisms. These two transmit malaria while *An. gambiae s.l.* and *Culex quinquefasciatus* transmit Bancroftian filariasis. *Anopheles gambiae* s.l. which originally was thought to be one species was later found to show peculiar eco-phenotypic adaptations and biochemical differences important in vectorial efficiency. Investigations into this problem has revealed that this species is actually a complex of six morphologically similar sibling species namely *Anopheles gambiae* s.s. Giles, *Anopheles arabiensis* (Patton, 1905), *Anopheles quadriannulatus* (Theobald, 1911), *Anopheles bwambae* (White, 1974), *Anopheles merus* Donitze and *Anopheles melas* (Theobald, 1903) (Colluzi and Sabatini, 1967). Studies on the distribution of *An. gambiae* sibling species in Kenya have shown that *An. gambiae* s.s. is commonly found in Nyanza and in the Coast provinces. *An.*

arabiensis is the most widespread, occurring in most parts of the country including Mwea and Turkana. *An. merus* is also known to be restricted to where it breeds in salt water such as the Coast. There are no records of the other three species in the country (Mosha and Subra, 1982; Division of Vector Borne Diseases (DVBD) Report, 1995). Of the three sibling species found in Kenya, *An. gambiae* s.s is probably the most efficient vector due to its narrow host range and endophilic behaviour (Taylor *et. al.*, 1990). Regarding other characteristics, studies carried out in Kenya indicate that the three sibling species are heterogenous in their breeding, feeding and resting habits (Highton *et al.*, 1979; Mosha and Mutero, 1982; Mosha and Subra, 1982; Mutero *et al.*, 1984). *An. gambiae* s.s. and *An. arabiensis* are sympatric over much of their range, but there seems to be some differences in their distribution and ecology. However, available data indicate that there are behavioural diffences between them. This contrast is useful in the understanding of the epidemiology of mosquitoes and in considering vector control strategies which can be employed.

As concerns *An. arabiensis*, conflicting generalisations on the ecology and behaviour often arise due to rather limited observations from a few localities (Service, 1970a; Service *et. al.*, 1978; White, 1974; Joshi *et al.*, 1975; Highton *et al.*, 1981; Molineaux and Gramiccia, 1980; Fontaine *et al.*, 1978). Molineaux and Gramiccia (1980) concluded that the failure to interrupt malaria transmission in the Garki area of northern Nigeria was due to a significant degree of outdoor resting by both *An. gambiae* s.l. and *An. arabiensis*. On the other hand it is considered that the

much greater impact achieved in Kisumu, Kenya when houses were sprayed with fenitrothion insecticide (Fontaine *et al.*, 1978), was due to the greater efficiency of this insecticide in killing indoor resting vectors but not due to greater endophily of the vectors. This shows that there is considerable variation in the degree of anthropophily and exophily exhibited by *An. arabiensis*. Coluzzi *et al.*, (1979) have shown that distribution and degree of exophily in both *An. gambiae* s.s and *An. arabiensis* is determined at least to some extent by chromosomal inversion polymorphism.

1.2 MALARIA IN KENYA

1.2.1 The status of malaria in Kenya

Malaria is a significant impediment to development in Kenya. Children suffer greatly every year resulting in a high absence rate from schools. Irrigated agricultural projects, resettlement schemes and industries probably experience most setbacks due to malaria in terms of time lost from work. A lot of working time among adults is usually lost due to malaria (Some, 1992). Agricultural development projects have created more opportunities for the vector mosquitoes to thrive due to the vast expanse surface of water. Mass movement to these malaria endemic areas by non-immune persons looking for employment has caused a burden on the existing health facilities. Areas where malaria was previously unknown such as Kericho, are now frequently experiencing epidemics with high morbidity and mortality (DVBD Report, 1994). Malaria also affects tourism, a leading foreign exchange earner which brings Kenya up to US$ 300 million annually. Due to limited or no laboratory facilities, especially at

dispensaries and health center levels, diagnosis of malaria is mainly based on signs and symptoms. This leads to overdiagnosis with consequences of excessive expenditure on drugs. In Kenya, malaria is the leading cause of morbidity accounting for approximately 30% of the out-patient illnesses reported in the health facilities. Approximately 6 million cases are reported annually (Health Information System (HIS), 1993). 5.1% of malaria patients admitted to our health facilities die and 10% of survivors have severe lasting effects (Ministry of Health (MOH), 1992). The disease remains a serious public health problem in areas where it is endemic. It is widespread in the Coast, most of Nyanza, Western and parts of Eastern, N. Eastern, Central and Rift Valley Provinces. Efforts to control the disease have been complicated as a result of development of strains of *Plasmodium falciparum* that are resistant to chloroquine the drug that is most widely used for treatment of malaria.

Out of four species of *Plasmodium* infecting man in Kenya, *Plasmodium falciparum* is the most prevalent. The species is found in all endemic areas, usually accounting for more that 80-90% of malaria infections. Most of the fatal cases of malaria are also due to *P. falciparum*. Among the other three malaria species *P. malariae* is more common than *P. ovale* and *P. vivax*. The latter is only occassionally reported.

1.2.2 Epidemiological setting in Kenya.

The definition of malaria endemicity is generally based on parasite rate, spleen rate and vector seasonality and abundance.

All the four factors determine the degree of transmission in a particular area.

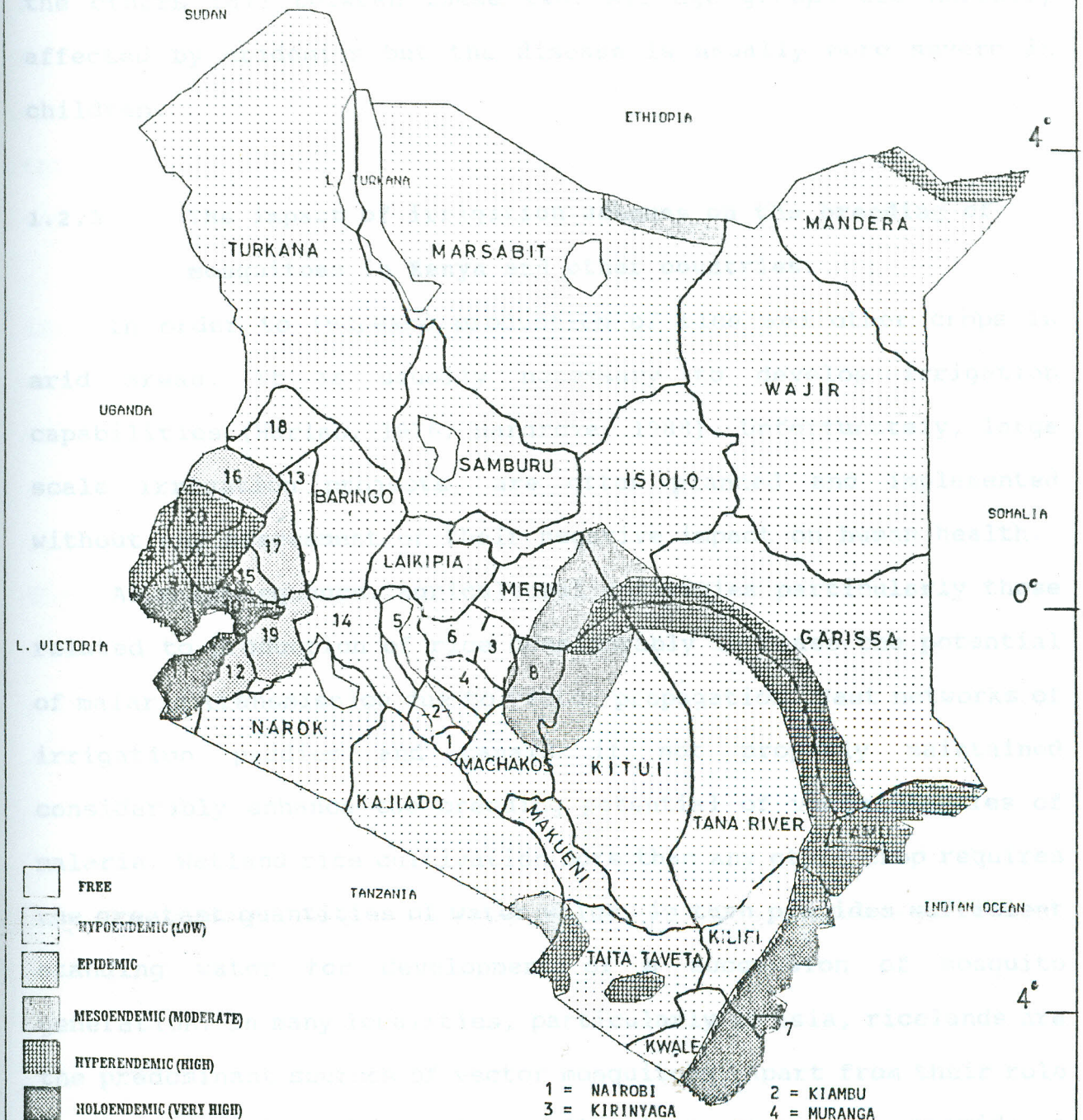
Under Stable malaria (Holoendemic) situation (Figure 1), transmission is more or less continuous throughout the year and especially in the Coast, Nyanza and Western Provinces. Malaria prevalence in the human population is generally between 50-75% and accounts for at least 30% of out-patient morbidity (HIS Statistical Bulletin, 1993). Morbidity and mortality are especially severe on infants and children under 5 years. However, infants born in such areas acquire some degree of passive immunity from their mothers, which helps to protect them against malaria in their first few months of life. Most adults and older children develop antibodies to malaria in stable malaria situation and can maintain high levels of clinical immunity. This immunity is lost to some degree by individuals under special circumstances including pregnancy, surgical operation, Sickle cell condition and HIV infection.

Unstable malaria (Mesoendemic) situation occurs in areas with seasonal increases in both morbidity and mortality. Mesoendemic areas in Kenya include Machakos, Kitui and Marigat. Malaria in these areas accounts for more than 40% of childhood morbidity and people of all age groups may suffer severe clinical attacks.

Epidemic malaria situation can be defined as a sudden increase in malaria cases above 50% of those usually observed in a given population at any one time. Epidemic malaria usually occurs in highland areas with an altitude between 1,500 m - 2,000 m above sea level. Since 1988 epidemics have become more frequent as evidenced by a dramatic increase in reported cases. In 1994, the areas

Figure 1. **Map showing endemicity of malaria in Kenya.**

ENDEMICITY OF MALARIA IN KENYA



Malaria Control Programme

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affected by malaria epidemic included the highlands (Kisii, Nyamira, Nandi), semi-arid areas (Narok, Turkana, West Pokot) and the others fall between these two. All age groups are normally affected by epidemics but the disease is usually more severe in children.

1.2.3 The impact of irrigation schemes on the breeding of mosquitoes in Kenya and other countries.

In order to increase production of rice and other crops in arid areas, it is usually necessary to develop irrigation capabilities (Harlan, 1976; Hargrove, 1988). Unfortunately, large scale irrigation projects, are often planned and implemented without any assessment of their negative impact on human health.

As a consequence, agricultural activities particularly those related to production of rice considerably increase the potential of malaria transmission due to vector propagation. Vast networks of irrigation paddies and canals if not properly maintained considerably enhance the breeding potential of vector species of malaria. Wetland rice cultivation more than any other crop requires the greatest quantities of water which, in turn provides sufficient standing water for development of a succession of mosquito generation. In many localities, particularly in Asia, ricelands are the predominant sources of vector mosquitoes. Apart from their role in mosquito breeding, rice cultivation may also provide a transmission environment for schistosomiasis and other human helminthic parasites (Loomis, 1976; Bradley and Narayan, 1987; Bergquist *et al.*, 1988 and Bradley, 1988).

The provision or amplification of breeding sites associated with irrigation has often resulted in increased prevalence of malaria, arboviral diseases and filariasis. Besides the expansion of larval habitat, irrigated rice fields may also increase vector competence by extending the survival rates of adult mosquitoes through the introduction of additional human and animal hosts in an environment of elevated humidity in otherwise arid climates.

Surtees *et al.*, (1970) carried out some studies at Ahero irrigation scheme on the mosquito population on the pilot scheme and in a nearby undisturbed area scheduled for development within the following two years. The studies were investigating the consequences of human interference in natural ecosystems, with special reference to mosquitoes and arbovirus infection in man. Their findings showed that in the irrigated area there was a 70-fold increase in adult *Anopheles gambiae* s.l. biting man, and concentration of the human population into new villages. Elsewhere, Harden *et al.*, (1967) was able to show that inland mosquito problems existed primarily in the irrigated rice-growing Delta of the Mississippi. In contrast, Hill and Cambournac (1941) were able to show that intermittent irrigation reduced the number of anopheline larvae by over 80% without any effect on rice yields.

Besides the effects of flooding, several other agricultural practices can further influence the level of mosquito production within irrigated ricelands. These include the use of fertilizers, pesticides, types of tillage, type of irrigation (especially the level and duration of standing water), cropping system and maintenance of canals.

The use of chemicals to control weeds and insect pests in rice fields may have the greatest impact on mosquito production. In several instances, agrochemicals, especially insecticides, have been credited with declines in mosquito populations and even reductions in vector-borne diseases (Cates, 1968; Kamimura and Katori, 1969; Bang and Self, 1971; Self *et al.*, 1973; Mogi *et al.*, 1980b; Chambers *et al.*, 1981, Mogi, 1987). In most cases, however, a resurgence in mosquito numbers results from the decimation of the more slowly rebounding predator populations (Washino *et al.*, 1972; Chandler and Highton, 1976; Service, 1977; Mogi, 1978b, 1981; Mogi *et al.*, 1980a; Schaefer *et al.*, 1981a, 1981b). Service (1977) while sampling larval and pupal populations of *Anopheles gambiae* complex in Kenya observed that insecticidal spraying of the rice fields killed both *An. gambiae* s.l. and predators. The former re-established themselves very quickly but reorganization by the predators was slower. This possibly accounted for apparent reduction in preadult mortality found in *An. gambiae* after spraying. The use of agricultural insecticides in ricelands has also been linked with the development of resistance in mosquitoes to insecticides used in public health (Brown and Pal, 1971; Georghiou, 1972, 1987; Nas, 1976; Brown, 1985; Herath and Joshi, 1986; WHO, 1986b; Way, 1987). Secondary effects of rice farming resulting in ecological changes due to certain practices such as use of machinery in lieu of ploughing using animals have been reported by Service (1984, 1989c). In this regard, Chambers *et al.*, (1981) also noted an increase in breeding sites in rice fields created by harvesting equipment. Flooded paddies in Kenya, Uganda

and Tanzania produce significant numbers of *An. arabiensis* in areas hyperendemic for malaria. In holoendemic areas, asynchronous planting of fields such as Ahero, Kenya, also maintains continual emergence of adult mosquitoes during most of the year (Chandler and Highton, 1975).

1.3 Factors determining survival of mosquito larvae.

The survival and physiological condition of larvae in rice fields depend on water chemistry and quality, plant related factors, amount of available food, density and composition of predator populations, inter- and intraspecific competition and several agricultural factors including; type of cropping system (single or multiple rice crops, rotation with other crops), type of irrigation, time of planting, agrochemical usage (including insecticides, herbicides, fertilizers) and the type of land preparation (tillage, levelling, etc). Other factors such as extremes in rainfall and temperature may catastrophically affect larval survival.

Several investigations have revealed major variations in larval abundance even in fields that are in close proximity with one another. In many cases only a small percentage of fields is responsible for the mosquito production. Bang and Pant (1983) reviewed several aspects of rice field that determine their suitability as larval habitats. The factors which included analyses of various environmental factors that influence the presence and population dynamics of riceland mosquitoes in specific settings have also been presented in several studies (Horsefall, 1942a; Case

and Washino, 1975; Chambers *et al.*, 1979; Andis and Meek, 1984; Mogi *et al.*, 1986; Mogi, 1981, 1984; Palchik and Washino, 1985; Pitcairn *et al.*, 1987; Sandoski *et al.*, 1987; Kramer and Garcia 1988; McLaughlin and Focks, 1990).

The following few sections outline some of the factors that are considered to be most important in influencing larval breeding.

1.3.1 Plant height and density.

Rice fields may be inhabited by a specific species of mosquito throughout all stages of plant growth (Chang *et al.*, 1950; Chow, 1969; Palchik and Washino, 1985). However, the influence on mosquito breeding depends on height and density of rice plants (illustrated in Figure 2.4, for Mwea rice irrigation scheme). The presence and density of certain plants can both negatively and positively affect oviposition and larval density (Rejmankova *et al.*, 1988). Densely planted short nursery rice as well as newly transplanted seedlings are reported to support prolific breeding by *An. gambiae* s.l. (Surtees, 1970; Surtees *et al.*, 1970; Chandler and Highton, 1975, 1976). Although *An. gambiae* s.l. is found most abundantly among rice plantation particularly when the rice crop is still young, Muirhead-Thompson (1951) and Simpson (1975) reported it from fields throughout all stages of growth. Mosquito species often observed in more established stands of rice are *An. pharoensis*, *An. coustani*, *An. subpictus*, *An. pallidus*, *An. philippinensis*, *An. varuna*, *An. barbirostris*, *Cx. poicilipes*, *Cx. univittatus*, and *Cx. antennatus*. Species that are found in the most mature stands of rice even just prior to harvest are: *An. ziemanni*,

An. aconitus, *An. nigerrimus* and *Cx. antennatus* (Surtees, 1970c; Surtees *et al.*, 1970; Chandler and Highton, 1975; Simpson, 1975; Snow, 1983; Rao, 1984; Carnevale and Robert, 1987; Robert *et al.*, 1988).

Chandler and Highton (1975) observed that the slurry of shallow muddy pools that followed rice transplanting stimulated intense breeding of *An. gambiae* s.l. and *An. pharoensis*. The two workers also reported that source and depth of water also influenced larval density. Unlike the *An. gambiae* complex, *An. funestus* is known to prefer breeding in feeder and drainage canals usually adjacent to rice paddies.

1.3.2 Temperature

Extremes of temperatures have been reported as limiting factors of riceland mosquitoes throughout the range of irrigated rice. Species such as *An. funestus* and *An. minimus* can be relatively intolerant of prolonged temperatures much in excess of 30°C. In contrast, *An. culicifacies* and other species that breed in open sunlight tolerate higher ranges of temperatures (Chambers *et al.*, 1979). Temperature and moisture are prime determinants for survival of floodwater mosquito eggs. The majority of fully embryonated eggs of *Ps. columbiae* for example, survive on dry moist soil for 9 months and are ready to hatch when inundated by spring rains (Chambers *et al.*, 1981).

1.3.3 Shade

Besides the attractiveness of decreased light to some species,

shade also provides regulation of high temperature that may be otherwise prohibitive to certain mosquitoes such as an *An. funestus* and *An. minimus* (Collins and Washino, 1979).

1.3.4 Proximity and abundance of host animals.

Many species of riceland mosquitoes, including several important vectors of human diseases, are zoophilic, and their population densities in rice fields are frequently influenced by host availability in the vicinity of breeding sites. A number of studies have elucidated the non human host preferences of riceland mosquitoes (Bue'i *et al.*, 1968; Pennington and Phelps, 1968; Wada *et al.*, 1970; Mitchell *et al.*, 1973; Chandler *et al.*, 1976; Joshi *et al.*, 1977; Karoji *et al.*, 1980; Kuntz *et al.*, 1982). Those on *Psorophora columbiae* have provided some of the most quantitative information on the influence of nearby animals on the abundance of larvae in rice fields (Chambers *et al.*, 1981; Williams and Meisch, 1981; Kuntz *et al.*, 1982; McLaughlin and Vidrine, 1987; Focks and McLaughlin, 1988; Focks *et al.*, 1988a, 1988b; McLaughlin and Focks, 1990). Chambers *et al.*, (1981) looked at the effects of cultural practices on mosquitoes breeding in the rice fields of three agroecosystems in North, Central and South Louisiana. He was able to show that the population density of *Ps. columbiae* increased with the introduction of cattle into the harvested fields which provided both host animals and hoofprint oviposition sites. Williams and Meisch (1981) compared the source of blood meal of mosquitoes captured from two areas of Arkansas country. The first one was concerned with rice production but livestock were extremely rare.

The other area was slightly upland and contained scattered herds of cattle, woodlands as well as rice. The results showed that cattle were the most important identified hosts of *An. quadrimaculatus*. Kuntz *et al.*, (1982) carried out studies on blood meal source of engorged female *Ps. columbiae* from traps set at a rice-farm site and a flood plain site in Texas. The results indicated that cattle and to some extent horses served as the primary sources of blood meals for the *Ps. columbiae* specimens. These results are again confirmed by McLaughlin *et al.*, (1987) in studies carried out in S.W. Louisiana.

1.4 Irrigation schemes and their impact on health in Kenya and other countries.

The link between irrigation and other agricultural practices, particularly in wetland rice production, and the increased prevalence of mosquito-borne diseases such as malaria, filariasis, Japanese encephalites (JE) and a variety of other zoonotic arboviruses has been investigated by many workers in the past (Gunasekara, 1919; Gill, 1930a, 1930b; Sen, 1935; Russell *et al.* 1942a; Senior, 1946; Hill and Cambournac, 1941; Holstein, 1954; Webbe, 1961; Surtees, 1970a, 1970c; Surtees *et al.*, 1970; McClelland, 1973; Sharma and Uprety, 1982; Luh, 1984a; Mogi, 1984; Service, 1984; 1989b, 1989c; Pozzi, 1986; Mulla *et al.*, 1987; Carnevale and Robert, 1987; Gratz, 1988; Bradley, 1988; Goonesekere and Amerasinghe, 1988; Ichimori, 1989). Although malaria is not currently endemic in the United states, in the past its occurrence was strongly correlated with rice cultivation in parts of the

Southeast and in Central valley of California (Barber *et al.*, 1926; Gray, 1956; Boyd, 1941; Faust, 1949; Freeborn, 1917; Henderson, 1952; Harden *et al.*, 1967; Garrity, 1988). Harden et al., (1967) was able to show that the inland mosquito problem existed primarily in the rice-growing Delta (Mississippi).

Ecological changes due to human activities have been responsible for some of the largest increases in the incidence of malaria and other vector-borne diseases. Conversely in certain instances, however, the drastic environmental changes that usually result from irrigated development projects have actually reduced the incidence of mosquito-borne disease by eliminating the breeding sites of effective local vectors. For instances, rice cultivation is known to have displaced effective malaria vectors with less competent mosquitoes or even non vectors in the Philippines, Malaysia, Burkina Faso and elsewhere (Ejercito, 1951; Najera, 1988; Service, 1989a).

Morbidity and mortality due to vector-borne diseases frequently increase as employment and settlement opportunities in newly opened irrigation schemes lure immunologically naive populations into endemic areas. In this way, infected immigrants also introduce malaria into areas previously free of malaria (Cambournac, 1978; Smith, 1972; Wessen, 1972; Service, 1984, 1989b; Kondrashin, 1986, 1987).

A combination of various components of a development project can also exacerbate the effects of a vector-borne disease. For example, the Mahaweli rice irrigation project in Sri Lanka created excellent breeding sites for culicine vectors of Japanese

encephalites virus, while concomitant pig farming provided optimal amplification hosts for the virus (Goonasekere and Amerasinghe, 1988). Similar examples linking Wetland rice development with potential increases in other vector-borne diseases including malaria in Kenya and other countries have been reported in various studies (Holstein, 1954; Surtees, 1970a, 1970c; Surtees *et al.*, 1970 and Simpson, 1975). Rice cultivation is also considered a major contributing factor in the epidemiology of malaria in Madagascar (Holstein, 1954; Zahar, 1985).

Malaria continues to be a significant human health problem, with over 2.6 billion persons living at risk of the disease worldwide. Clyde (1987) contends that there has been little recent progress in reducing the prevalence of the disease in several countries, and in many areas the situation has actually deteriorated. Malaria is still a significant cause of child mortality (Bruce-Chwatt, 1987), especially in Africa South of the Sahara where approximately 80% of all malaria cases occur (Breman and Campbell, 1988). In addition to the impact of malaria on human health, the disease may produce several severe social and economic effects. These are reviewed by Rosenfield (1986) and Wernsdorfer and Wernsdorfer (1988). They include eighty five species of *Anopheles* mosquitoes which have been associated with riceland all over the world and fifty five have been reported as vectors or suspected as being vectors of malaria. An increase in vector production due to rice cultivation can result in higher prevalence rates of malaria and an extension of the transmission season. However, in areas where malaria is stable and holoendemic, there

may be little significant change in morbidity and mortality due to the disease (Service, 1984).

1.5 Malaria control.

Historically, malaria control activities have been important components of the Kenya Government health programmes. Prior to the 1950s, substantial efforts were maintained to limit urban malaria with environmental measures for instance house screening, entomological surveillance and actual vector control.

In the 1950s there was renewed effort globally to achieve malaria eradication. The programme emphasised vector control and environmental management. Unfortunately, in the Kenyan situation as well as in the rest of the world it soon became clear that eradication of malaria was an unrealistic goal, that was impossible to achieve. Since then emphasis has been placed on malaria control. Malaria control can be achieved through direct or indirect measures. Direct measures include destruction of the malaria parasite either in the host through chemotherapy or in the vector through killing mosquitoes. All other methods fall under indirect measures.

Control of mosquitoes is undoubtedly the best method of protecting a community against the disease. Early control methods relied on "Source reduction" by eliminating the breeding sites. This practice was however abandoned later, in favour of residual insecticides. Environmental management for vector control has nevertheless regained its popularity and is now recommended by WHO. Various vector control methods commonly used in different countries

are reviewed in the following sections.

1.5.1 Chemical control of mosquitoes

For a long time the use of chemicals to control mosquitoes has been used against both adult and larval stages. Pyrethrum insecticide was the first to be used and it gave good results. More effective residual insecticides such as DDT however, soon replaced pyrethrum. Effectiveness of DDT in controlling mosquitoes lies in its residual properties. During recent times the realisation of various problems associated with large scale chemical usage against insect pests, has nevertheless made authorities look for other ways that could be used as alternatives for effectively controlling mosquitoes (Brown, 1985).

1.5.2 Environmental Management

The advantages and limitations of environmental management for the control of mosquitoes has been discussed by several workers in the past (WHO, 1982b; Rafatjah, 1988; Bos and Mills, 1987). Specific use of enviromental management techniques for mosquito control in rice fields is presented in detail by several authors and has been recently reviewed (Mather and That, 1984; Mogi, 1984, 1988; Meyer *et al.*, 1984; Amerasinghe, 1987; Goonasekere and Amerasinghe, 1988; and Wada, 1988). The use of Azolla , a floating fern with the advantage of providing a useful source of green manure as a crop fertilizer has also been studied as a surface agent to smother mosquito breeding sites (Baolin, 1988a).

Regarding rice fields, water management that permits optimum

growth of rice plants without adequate time for larval development is usually recommended. One of the most commonly used methods has been irrigation of paddy fields on an intermittent basis. This strategy for control of malaria vectors has been successfully used in several areas such as India (Russell and Rao, 1940; Knipe and Russell, 1942; Russell *et al.*, 1942b); Portugal (Hill and Cambournac, 1941; Japan (Mogi, 1988); Taiwan (Cates, 1968); Korea (WHO, 1983) and China (Luh, 1984b, Ge Fenxiang *et al.*, 1981 and Pal, 1982).

Another water management strategy involves the flushing of larvae from rice fields. Where currents due to heavy rainfall are sufficient, natural flushing may account for significant reduction in larval numbers (Heathcote, 1970; Surtees, 1970b). The prerequisites for use of this strategy are presented by Mogi (1984) and as excess irrigation water. Kiker and Knipe (1949) described methods for the fluctuation of canal levels that are designed to reduce vector populations. Induction of sufficient current through the entire field system may probably make it possible to kill concentrations of larvae. The routine and effective maintenance of irrigation systems to promote proper drainage and to prevent leakage and overflow from canals which, if neglected usually result in subsequent creation of breeding sites as an essential component for the prevention of agricultural associated malaria (Freeborn, 1917; Russell *et al.*, 1942a; Sharma and Uprety, 1982 and Sharma, 1987). Heathcote, (1970) was able to show that *An. arabiensis* larval density was closely correlated with agricultural practices throughout the year. For example, the planting of rice seedling

nursery provides suitable breeding sites for mosquito larvae (Mogi, 1984). The production of several species of riceland mosquitoes is not solely the result of rice field breeding, but also due to associated habitats such as canals. Kiker and Knipe (1949) described methods for the fluctuation of canal levels that are designed to reduce vector populations. Routine and effective maintenance of irrigation systems to promote proper drainage and to prevent leakage and overflow from canals normally reduces vector breeding (Freeborn, 1917; Russell *et al.*, 1942a; Sharma and Uprety, 1982 and Sharma, 1987).

1.5.3 Biological control

This method of control is based on the introduction into the environment of various pathogens and predators for killing insect vectors of diseases (Luh, 1978). Such agents range from viruses, bacteria, protozoa, fungi plants and nematodes to natural predators such as larvivorous fish. Attention has been given to *Bacillus thuringiensis* serotype H-14 whose spores produce toxins that are potent gut poison when ingested by mosquitoes but harmless to animals and man (WHO, 1982). *Bacillus sphaericus* is more promising because apart from being harmless to man and animals it can multiply even in polluted water.

Fungi of the genus *Coelomomyces* have been studied. They are promising but their cultivations are currently under study as biological control agents. *Romanomermis culicivorax* despite showing potential to reduce larval populations and to survive in a variety of habitats, is still being evaluated (WHO, 1982). Predatory

mosquitoes of the genus *Toxorhynchites*, have also been studied but it has now been realised that they can only be used in the control of container breeding mosquitoes (WHO, 1982).

1.5.4 Modification of human behaviour or habitation.

Another aspect of human behaviour involves protection against mosquito bites through modification of human behaviour or habitation (WHO, 1982b). Personal protection includes screening of windows and doors, and use of protective clothing, repellants and bed nets. The use of personal interventions that prevent human-mosquito contact have played a major role in the reduction or elimination of vector-borne diseases such as malaria from temperate and subtropical regions of more developed countries.

1.5.5 The role of Zooprophylaxis in Malaria Control.

Zooprophylaxis involves the use of wild or domestic animals which are not reservoirs of a particular disease to divert host seeking vectors from potential human hosts of that disease (WHO, 1982b). In the case of malaria transmission, WHO (1982b) regards Zooprophylaxis as being doubly effective as a control measure. Since humans are the only important vertebrate reservoirs of the malaria parasites, diversion of infected mosquitoes to other host species decreases transmission and prevents further amplification of the pathogen. Several vectors of malaria actually have rather low human blood indices and show marked preference for cattle and other warm-blooded animals. By placing livestock close to human habitation, especially between houses and breeding sites,

significant reduction of malaria transmission may be obtained when zoophilic anophelines, such as *An. albimanus*, *An. sinensis*, *An. aconitus* and *An. annularis* are the primary vectors.

McLaughlin *et al.*, (1989) and Nasci *et al.*, (1990) reported on the treatment of cattle with pyrethroid insecticides to kill rather than simply divert host seeking *An. quadrimaculatus*. Nasci *et al.*, (1990) were able to show from their results that host management by permethrin treatment has potential for controlling *An. quadrimaculatus* and *Ps. columbiae* populations, and especially on cattle because they are highly attractive to riceland mosquitoes in Lousiana. McLaughlin and Focks (1990) suggest that livestock can be used to concentrate mosquitoes and make them available for suppression measures. Additional detail on the use of zooprophylaxis is provided in several studies (Russell *et al.*, 1963; WHO, 1982b; Sandosham and Thomas, 1983 and Schultz, 1989). Schultz (1989) was able to show that positioning carabao (water buffalo, *Bulbalus bulbalis*) around the periphery of a village but away from any house might reduce malaria transmission to man significantly. Extensive studies have been carried out in irrigation schemes in other countries and Ahero Irrigation scheme in Kenya. In Mwea Tebere Irrigation scheme the studies that have been carried out have mainly dealt with the malaria vector bionomics but there has been no attempt to link vector behaviour to the disease pattern.

1.6 JUSTIFICATION

There is a general assumption that the incidence of malaria in rice irrigation schemes is high. This is due to the flooding of rice paddies for long periods, which enhances the breeding potential of mosquitoes especially the vectors of disease organisms. The effects of modification by man of his physical and biological environment in relation to disease prevalence has been widely reported. Various workers have shown that ricefields are capable of producing common species of mosquitoes including vectors of malaria in vast numbers. Morbidity and mortality due to water-related vector-borne diseases frequently increase when immunologically naive populations concentrate into irrigated endemic areas in search of employment and settlement. This situation can also be compounded by the introduction of malaria by infected people into a previously malaria free area.

Flooding of rice paddies in irrigation schemes no doubt enhances breeding potential of mosquitoes and more so the vectors of disease organisms. This usually results in an increase in malaria transmission but we are not certain as to what extent this happens in the Mwea scheme especially in relation to other similar irrigation schemes elsewhere in Kenya. The assumption on high incidence of malaria in rice irrigation schemes holds true for the Ahero irrigation scheme because it lies in the holoendemic area but there is no information on Mwea Tebere.

Studies on the ecology and behaviour of *An. arabiensis* is essential if we have to understand that day time resting sites of mosquitoes are governed by certain biological, physical and

environmental factors. Proper planning, execution and evaluation of anti-vector measures have to be based on a perfect knowledge of the bionomics of the vector. Presently, environmental management of vector control emphasizes on methods that could be sustained by the community, for example the use of pyrethroid impregnated curtains and screens or bednets in houses as well as zooprophylaxis. This is based on the principle that mosquitoes biting man indoors will probably rest on walls for sometime. In so doing, they come into contact with the residual insecticide on the impregnated bednets which will prevent them from living long enough to sustain malaria transmission. In cases where beds are not available, for instance in rural areas or refugee camps, insecticide impregnated screens and cloth if placed round the houses would probably be equally effective as bednets in protecting all members of the family. Knowledge on zooprophylaxis could be experimented on as a control method against man-vector contact, especially in an area in which the vector exhibits strong natural exophily and zoophily.

Some studies have been carried out by several workers on the ecology and behaviour of *An. arabiensis* sibling species in the Kano plains irrigation scheme at Ahero (Chandler and Highton, 1975, Highton, 1979; Service, 1977). Parallel studies have been carried out in Mwea Tebere irrigation settlement scheme (Mutero, 1985; Mukiama, 1987). The work carried out in Mwea Tebere did not satisfactorily cover aspects on malaria prevalence rates. There is still a lot of work to be done in this location which is an area of economic importance. The difference between the two Kenyan irrigation schemes is that Ahero lies in an area with large numbers

of *An. gambiae* s.s. mosquitoes throughout the year and hence there is malaria transmission at all times. The paddies at Mwea scheme are flooded for most part of the year between 9-10 months. Mosquito numbers may therefore fluctuate periodically, leading to seasonal transmission of malaria. In addition to determining the pattern of mosquito population fluctuations, a better knowledge on the exophily and endophily in *An. arabiensis* would go a long way to enabling us improve existing vector control strategies. The fact that malaria transmission in Mwea irrigation scheme is seasonal is advantageous because if we are equipped with proper understanding of the preferred vector resting sites, malaria transmission could be interrupted and kept at levels below economic importance. This study covered certain important aspects on mosquito seasonal variation, diversity, feeding and resting behaviour. Since findings on mosquitoes alone could not sufficiently give information on the magnitude of the impact of Mwea irrigation scheme on disease transmission, further studies on the relationship to malaria prevalence in the human population were also considered necessary.

1.7 Objectives

The main objectives of the study were:

1. To assess the impact of rice irrigation practices on
   i) Variation in mosquito species diversity and relative population density.
   ii) Malaria infection rates in both human and mosquito populations.
2. To compare the attractiveness of human and animal hosts

to different species of mosquitoes.

3. To investigate resting habits of *An. arabiensis* in Mwea and to correlate observed patterns with various environmental factors among them:
Temperature, rainfall and humidity; availability of hosts such as cattle tethered outdoors; and presence of man made outdoor shelters such as brick pits.

CHAPTER 2

2. GENERAL MATERIALS AND METHODS.

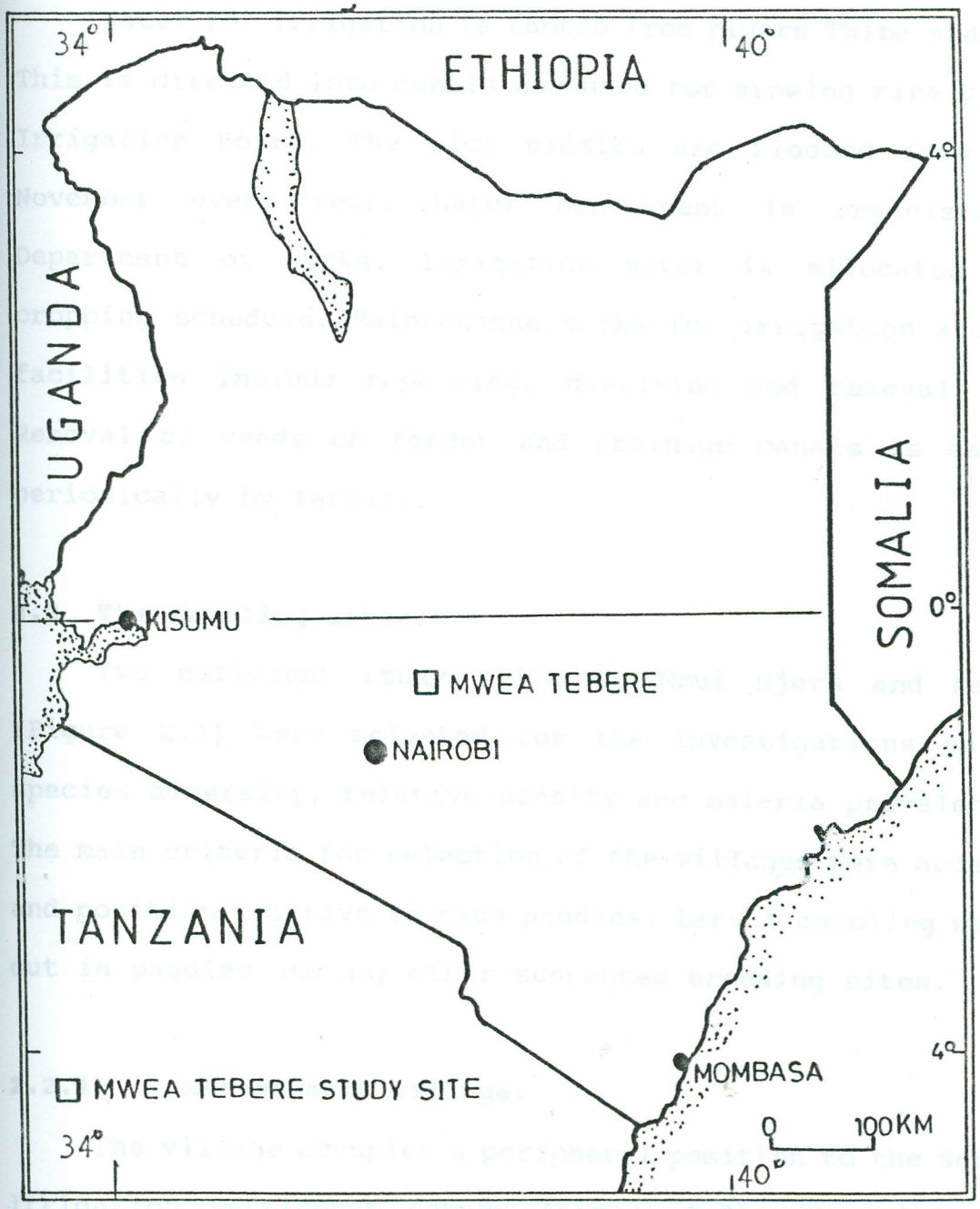
2.1 The study area.

The Mwea irrigation settlement scheme lies approximately 110 Km north-east of Nairobi near Mount Kenya on latitude $0^0.5'$ South and longitude $37^0.6'$ East (Figure 2) and is situated at 1159m above sea level. The settlement scheme was started for rice production in 1954 by the colonial government using detainee labour. It has expanded gradually and currently covers an area of 5,800 hectares. The scheme is still undergoing expansion through a Japanese aid programme to cover a total of 8700 hectares by the year 2000. The scheme was taken over by the National Irrigation Board in 1966 from the Ministry of Agriculture. The scheme settles farmers who were landless but mainly originated from Kirinyaga and the surrounding areas.

Overall, the Mwea irrigation settlement scheme has five irrigation sections divided into two parts according to water source for irrigation which include Nyamindi (Tebere) and Thiba (Mwea, Thiba, Wamumu and Karaba). The general layout of the area comprises of nucleus villages which lie within or adjacent to rice paddies. There are forty villages in the scheme. The total number of tenant farmers is 3,250, with an average family size of 8. The population in Mwea irrigation settlement scheme was 44,600 according to the 1989 census. The average population growth for Kirinyaga district is 3.15%, hence by 1994 the projected population was 52,000.

The soil is composed of Olivine basalt which erupted from

Figure 2. **Map of Kenya showing the Mwea Tebere Irrigation Settlement Scheme.**



Mount Kenya and is covered with fine textured clay. The annual rainfall ranges from 780mm to 1270mm with long rains in March to May and short rains in October to December. The daily temperature ranges from 15.6°C to 28.6°C. The average relative humidity is 64.3%.

Water for irrigation is tapped from rivers Thiba and Nyamindi. This is directed into canals and used for growing rice by National Irrigation Board. The rice paddies are flooded from March to November every year. Water management is organised by the Department of works. Irrigation water is allocated based on cropping schedule. Maintenance works for irrigation and drainage facilities include repairing, desilting and removal of weeds. Removal of weeds on feeder and drainage canals is carried out periodically by farmers.

2.2 The sampling sites.

Two different study villages, Mbui Njeru and Mathangauta (Figure 2.1) were selected for the investigations on mosquito species diversity, relative density and malaria prevalence. The main criteria for selection of the villages were accessibility and position relative to rice paddies. Larval sampling was carried out in paddies and any other suspected breeding sites.

2.2.1 Mathangauta village.

The village occupies a peripheral position to the North of the Irrigation Settlement scheme (Figure 2.2). The village has 78 households comprising a total of 198 housing units. The population

Figure 2.1. **Sketch Map of Mwea irrigation Scheme differentiati irrigated and non-irrigated areas.**

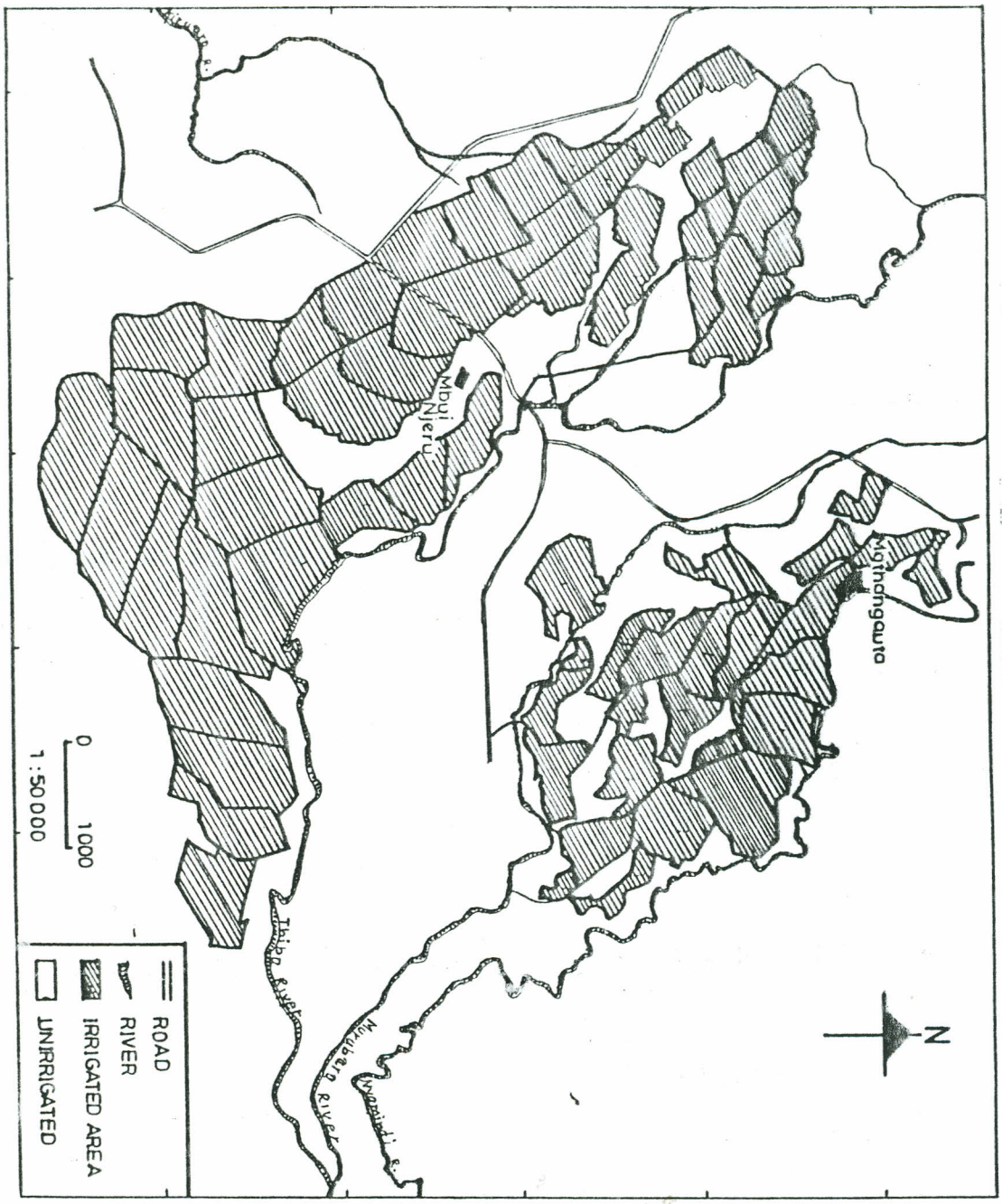
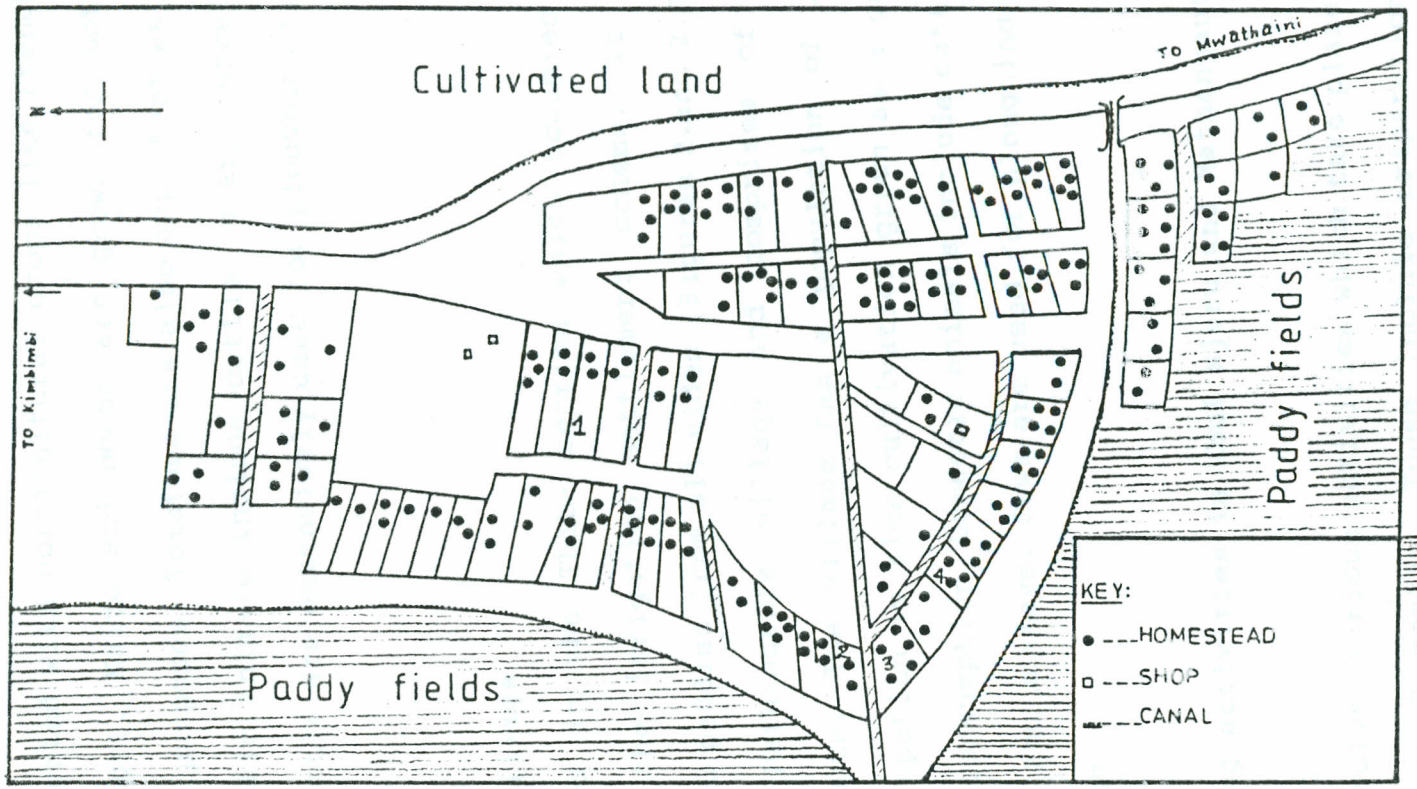

Mbui Njeru
Mutunguru
Thiba river
Nyamindi river
N
ROAD
RIVER
IRRIGATED AREA
UNIRRIGATED
0
1000
1:50000

Figure 2.2. **The sketch plan of Mathangauta village showing the households selected for mosquito sampling.**



Appr. Scale 1:15 Metres

comprises 570 people, 260 (45%) of whom are adults. The Agricultural occupation in this village is diversified. Rice is the major cash crop supplemented with horticultural crops like French beans produced for export. Maize and beans are grown for both domestic and commercial purposes. Tomatoes are also important as a local cash crop. Domestic animals include cattle, goats, sheep, chicken and donkeys. Cattle are extensively used for ploughing the rice paddies and farms.

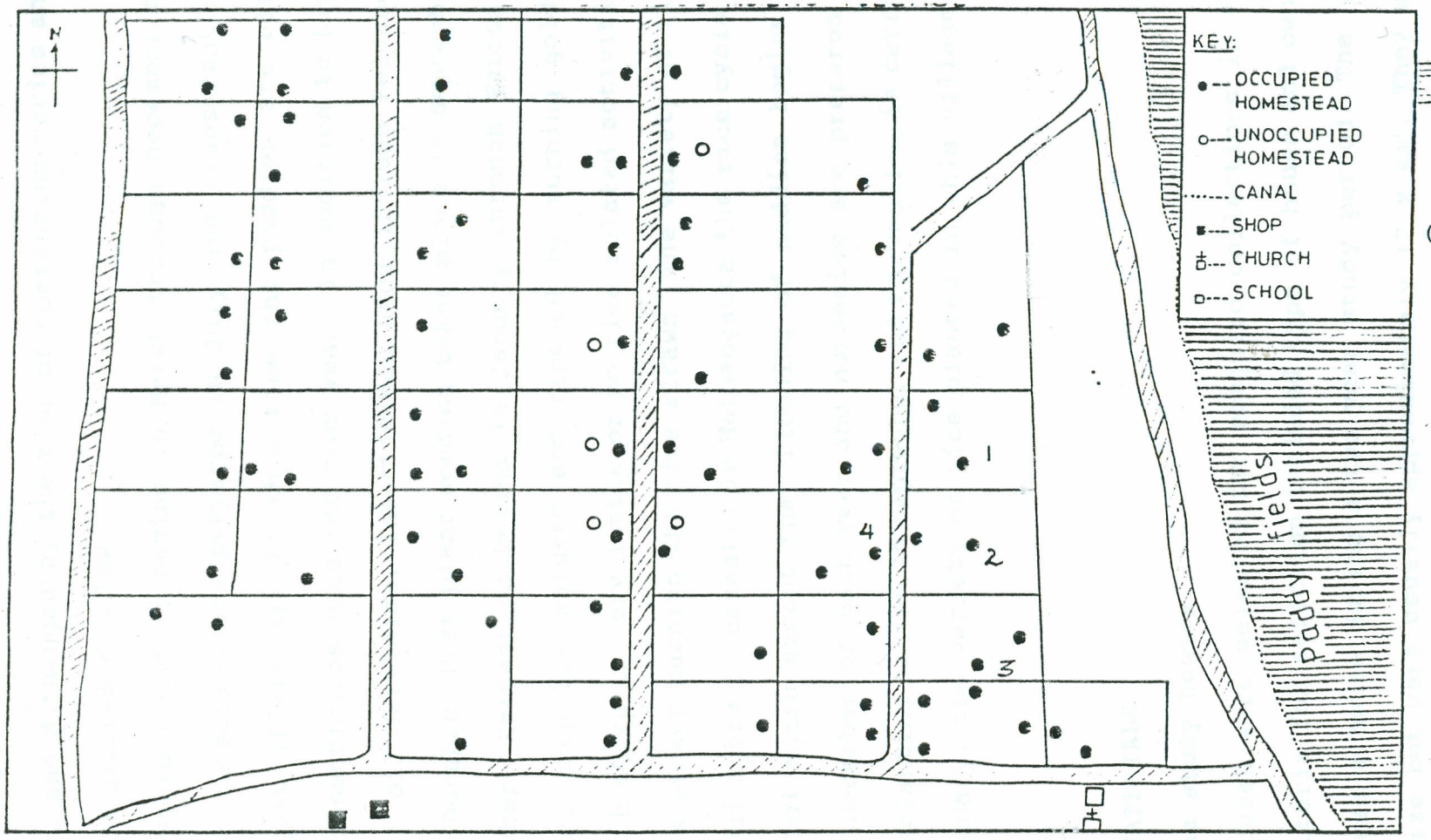
2.2.2 Mbui Njeru village

This village lies in the Thiba section which occupies a central position of the irrigation settlement scheme. It is surrounded by irrigated paddies from all sides (Figures 2 and 2.3). It is smaller than Mathangauta village and comprises of 42 households with 70 huts. The village has a population of 268 people. The major occupation is rice cultivation grown as a cash crop and for domestic consumption. Domestic animals include cattle, goats, sheep, chicken and donkeys. Cows are used for ploughing the rice paddies and farms.

2.2.3 Rice growing activities in Mbui Njeru and Mathangauta villages

Rice growing involves various activities which take place for a period lasting over 3 months. These include preparation of nurseries, transplanting, tillering and harvestng. The level of water in the paddies is usually topped up or reduced as the need arises throughout the rice growing activities as illustrated in

Figure 2.3. **The sketch plan of Mbui Njeru village showing th households selected for mosquito sampling.**



Appr. Scale 1:15 Metres

figure 2.4. Although similar rice growing activities take place in both Mbui Njeru and Mathangauta, the time of commencing varies and the details are discussed below.

In Mbui Njeru flooding begins in March through December of each year. The nurseries are prepared in July and transplanting begins in August (Plate 1). At this time the paddies are also sprayed with insecticides once per crop year. In addition to high spreading (HS) oil larvicide, insecticides used include Feldene, Sumithion and Dursban. Post plant weeding takes place in September through December. Harvesting begins in January through February after the rice crop has matured and ripened by turning golden brown. In March there is very little or no rice related activities in the paddies except burning the rice straws. The variety of rice planted in Mbui Njeru is Basmati. In Mathangauta the rice cycle is similar to Mbui Njeru except that flooding of paddies begins in July through December of each year and nurseries are prepared in August. Transplanting begins in September and harvesting is carried out after January. The variety of rice planted in this village is Sindano.

2.3 STUDY MATERIALS.

2.3.1 The study houses.

Four houses were selected for mosquito collections in each village. Criteria for selection included type of house and owners consent to use a house during a two year study period. The huts varied in size but were usually approximately 12 x 4m^2. They were basically composed of three rooms with slight variations in size.

Figure 2.4. **Rice growing activities and water management in Mw ricefields**

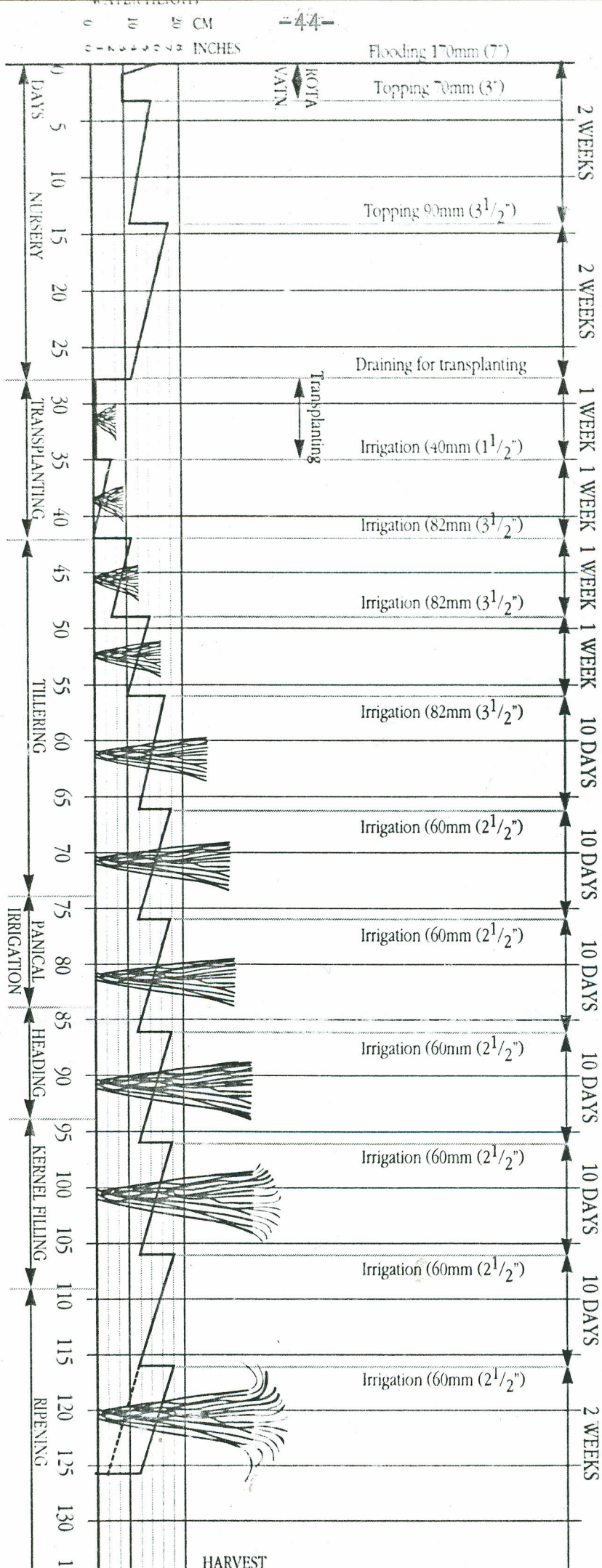

WATER HEIGHT
0 10 20 CM
0 5 10 INCHES
DAYS
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130
NURSERY
TRANSPLANTING
TILLERING
PANICAL IRRIGATION
HEADING
KERNEL FILLING
RIPENING
HARVEST
ROTA VATN
Transplanting
Flooding 170mm (7")
Topping 70mm (3")
Topping 90mm (3 1/2")
Draining for transplanting
Irrigation (40mm (1 1/2")
Irrigation (82mm (3 1/2")
Irrigation (82mm (3 1/2")
Irrigation (82mm (3 1/2")
Irrigation (60mm (2 1/2")
Irrigation (60mm (2 1/2")
Irrigation (60mm (2 1/2")
Irrigation (60mm (2 1/2")
Irrigation (60mm (2 1/2")
Irrigation (60mm (2 1/2")
2 WEEKS
2 WEEKS
1 WEEK
1 WEEK
1 WEEK
1 WEEK
10 DAYS
10 DAYS
10 DAYS
10 DAYS
10 DAYS
10 DAYS
2 WEEKS

Plate 1. **Section of Mwea irrigation settlement scheme showing flooded paddies, rice seedling nursery, canals and Mbui Njeru village in the background**

The rooms included a sitting room measuring approximately 4 x 4m^2 and two bedrooms. Occasionally, one of the rooms was used as a store for piling of sacks of harvested rice. The sacks provide very good resting surface for sheltering mosquitoes.

2.3.2 Mosquito Collection methods

Three collection methods were used to sample adult mosquitoes indoors. They included the hand catch (HC) method using battery powered aspirators, pyrethrum spray catch (PSC) method and the CDC light trap collection method. Outdoor resting adult mosquitoes were collected using the hand catch (HC) collection method. Mosquito larvae were collected by using the dipper method. (Details on these collection methods have been described further in each relevant chapter).

2.4. MALARIA INFECTION RATES

The incidence of malaria was determined by studying the infection rates both in the adult mosquitoes and human population. Two methods were used in the case of adult mosquitoes which included 1) dissections of adults and 2) the ELISA method.

The objectives of these studies was to incriminate the vector and establish the sporozoite rate. The two methods were used to complement each other because with dissections, the requirements are that the mosquitoes have to be alive in order for sporozoites to be observed. If the mosquitoes died before dissections, then these were preserved and processed using the ELISA method because it allows determination of sporozoites on dead mosquitoes.

2.4.1. DETERMINATION OF SPOROZOITE AND OOCYST RATE IN ADULT MOSQUITOES BY DISSECTIONS

The prevalence of malaria parasite infection rate in adult mosquitoes was determined by the dissection of salivary glands and mid-gut to look for sporozoites. Adult female *An. arabiensis* and *An. funestus* had their salivary glands dissected for sporozoites and midgut for oocysts to determine the sporozoite rate and oocyst rate respectively.

2.4.2. DETERMINATION OF SPOROZOITE RATE IN ADULT MOSQUITOES USING ELISA METHOD.

The incidence of malaria sporozoite rate in the adult mosquito vectors was also studied using the Enzyme-linked Immunosorbent Assay (ELISA) test. The test procedure is described below (Wirtz *et al.*, 1987).

ELISAs were developed to detect *P. falciparum* and *P. vivax* circumsporozoite (CS) proteins in infected mosquitoes. The sensitivity and specificity of the ELISAs are based on the use of monoclonal antibodies (MAbs) produced against sporozoites isolated from the salivary glands of infected mosquitoes. ELISAs can be performed on fresh, frozen, or dried specimens.

The "sandwich" ELISA is begun by adsorption of the capture MAb to the wells of a microtitration plate. After 1/2 hour incubation at room temperature the well contents are aspirated and the remaining active binding sites on the plate are blocked with blocking buffer. Mosquitoes to be tested are ground in blocking buffer containing Nonidet P-40, diluted with blocking buffer and

aliquots added to wells. Positive and negative controls are also added to specific wells at this time; recombinant proteins are used for the quantitative positive controls. If CS antigen is present it will form an antigen-antibody complex with the capture MAb. After 2 hours incubation, the mosquito triturate is aspirated and the wells are washed. The respective peroxidase-linked MAb is then added to the wells, completing the formation of the "sandwich". After 1 hour incubation the well contents are aspirated, the plate is washed and the clear peroxidase substrate solution is added. As the peroxidase enzyme reacts with the substrate a dark green product is formed, the intensity of the colour being relative to the amount of CS antigen present in the test sample. Results are read visually or at 414 nm using an ELISA plate reader 30 or 60 minutes after the substrate has been added.

2.4.3 DETERMINATION OF MALARIA PREVALENCE IN THE ADULT HUMAN POPULATION

The incidence of malaria in the adult population was determined by collecting blood smears on slides from residents of Mathangauta and Mbui Njeru villages once every month from 1989 to 1990. The cases of malaria confirmed in the DVBD laboratory and reported at the Kimbimbi health centre were also recorded during this period. During the second year (1990) malaria surveys were conducted in other villages within the irrigation scheme to compare the incidence of malaria in these villages with Mbui Njeru and Mathangauta.

CHAPTER 3

3. MOSQUITO SPECIES DIVERSITY AND RELATIVE POPULATION DENSITY.

3.1 Introduction

The study of insect species composition or diversity within a given area is an essential part of ecological research. With regard to mosquitoes, spatial and temporal distributions of different species is governed by various factors such as, presence of breeding sites, host availability, climatic factors and availability of resting sites (Bhatt *et al.*, 1989). Related species which thrive on the same types of food and live in similar places may limit the distribution of one another through competition. Evidence of competition is indicated by the observation that the geographical distributions of two closely related species do not overlap. Secondly, the observation that in the absence of a hypothetical species A, Species B lives in a wider range of habitats (Krebs, 1972). In nature the species of mosquitoes breeding in an area may not be stable for long periods due to short term changes such as flash rainfall in the larval habitat. Such changes may either occur naturally or be due to human activity. This results in ecological species succession whereby different mosquito species are favoured at different times of the year.

There are several methods employed for sampling different mosquito species. These have already been briefly referred to in Chapter 2. Sampling is central to data collection including studies on mosquitoes, as it is the procedure through which all the information relating to species composition, density, distribution, behaviour, activity patterns and interaction with disease causing

organisms such as plasmodium, microfilariae and viruses can be obtained. Data from sampling usually forms a solid foundation upon which strategies for mosquito control can be developed and evaluated. For instance, accurate assessment of larval and adult populations of mosquitoes before and after control measures is crucial in determining the level and timing of interventions as well as in assessing their success or failure in known situations.

Among the collection methods employed, the hand catch and pyrethrum spray catch methods are respectively used to estimate the relative and absolute density of daytime indoor resting mosquitoes. The hand catch method has the advantage that all the mosquitoes collected are alive, thus, facilitating dissecting them to determine different stages of malaria parasites such as sporozoites and oocysts. The light trap is used in sampling mosquitoes entering houses to feed on humans or rest. Its attractiveness is influenced by various factors including the intensity of light produced by the bulb (Robinson, 1952; Barr *et al.*, 1960; de Jong, 1967). The simultaneous use of various sampling methods is considered useful in ensuring that population heterogeneities due to behavioural or physiological factors are catered for accordingly.

Larval collection enables determination of breeding places of relevant mosquitoes transmitting diseases in a given area. The adult female mosquito is responsible for selection of the breeding habitat. This selection is governed by intrinsic genetic responses (Service, 1976). Different breeding sites for mosquito larvae have been described by several workers (Bates, 1949; Hopkins, 1952; Mattingly, 1969; Andis *et. al.*, 1983) who have been able to show

that certain mosquito species such as *Cx. quinquefasciatus*, breed in different types of habitats such as ground pools, containers and pit latrines while other species such as *An. gambiae*, *An. funestus* are more restricted in their choices. Surveys are normally carried out throughout the year to determine the seasonal variation of vector mosquitoes.

The aim of this study was to determine the monthly and seasonal variations in mosquito species composition, behaviour and relative density in the Mwea Rice Irrigation Scheme.

Special emphasis was placed on the influence of temperature, rainfall, humidity and rice cultivation practices, particularly with regard to populations of *An. arabiensis* and *An. funestus* the two species that are responsible for transmission of malaria in the area.

3.2 MATERIALS AND METHODS

3.2.1 Collection methods and sites

3.2.2 Day-time Indoor resting adult mosquitoes

Few mosquito species regularly rest in human and animal habitations. Those that do are often important vectors of malaria, filariasis as well as arboviruses. The resting mosquitoes are usually caught from these shelters with aspirators or by knock-down pyrethrum spray collections. Mosquitoes were sampled alternately for seven days in each of the two villages for a total of fourteen sampling days every month. Mosquito collections were made from four houses in each of the two villages. The houses were randomly selected and also on the basis of the owners consent and presence

of eaves.

Collections using battery operated aspirators were conducted from 0630 hrs and for fifteen minutes in each of the rooms of the houses sampled. Collections made using the spray catch method were done on separate days but was also started at 0630 hrs. Thereafter, a time lapse of two days was maintained after each spray sheet collection to allow the effects of the insecticide to wear off so as not to influence the number of mosquitoes in subsequent collections.

3.2.3 Collection of adult mosquitoes active inside houses

A CDC light trap (Plate 2) was set up overnight in one house of each village from 1830 to 0700 hrs for three consecutive nights. The light trap was placed in the bedroom and hang about 5 metres from the ground. Collections made using light traps were based on the fact that adult mosquitoes are attracted to the source of bulb light and are consequently sucked and retained into the collecting net.

3.2.4 Collection of Outdoor resting adult mosquitoes

Outdoor populations of resting mosquitoes are usually widely distributed in an area and not concentrated in discrete units. Most mosquito species rest exclusively outdoors in natural habitats. Although *An. gambiae s.l.* is generally regarded as being endophilic, a certain proportion of the population may continue to rest outdoors (Gillies, 1954) despite the availability of suitable indoor resting sites. Past work has shown that outdoor resting

Plate 2. **CDC light trap set in a hut for collection of active mosquitoes.**

shelters include many types of habitats among them animal burrows, hollows in trees, holes at the base of termite mounds, crevices, tree trunks and within vegetation (Harwood, 1962; Service, 1969; Breeland, 1972a).

In the present study, outdoor resting mosquitoes in Mathangauta village were sampled from burrow pits made by the local community when making bricks (Plate 3). In Mbui Njeru village, sampling of the outdoor population was carried out in pit traps specifically dug out for this study. Pit traps were dug out in Mbui Njeru to simulate those found in Mathangauta. In either case battery operated aspirators were used to collect the resting mosquitoes. Sampling was conducted from 0800 hrs for fifteen minutes by three collectors.

3.3 Adult Mosquito species identification

All the adult mosquitoes collected were identified to species using external morphological features. *An. gambiae s.l.* were in addition to taxonomic identification separated into different physiological stages according to the appearance of the abdomen. This was done to determine the resting behaviour of the adult mosquitoes.

3.4 Larval sampling in Mbui Njeru and Mathangauta villages.

Monthly collections of larvae were made from various possible breeding sites within the rice ecosystem such as paddies, nursery plots, feeder and drainage canals as well as seepage pools (Plate 4). The dipper used for sampling consisted of a soup ladle with a

Plate 3. **Burrow pits dug out for soil used in making mud bricks, showing outdoor resting sites for mosquitoes.**

Plate 4. **Sampling larvae from a paddy nursery with rice seedling using a laddle.**

capacity of 270ml and measuring 8cm in diameter.

Ten paddies and two nurseries in each of the two villages, were sampled for larvae using the dipper method. Five samples each consisting of 20 dips were taken at the sampling site once a week during the sampling period. The larvae collected were identified immediately or preserved in lactophenol to facilitate identification later.

3.5 Determination of height of rice

The height of plants growing in the paddies from which larvae were sampled was measured and recorded every month. The exercise involved random plucking of plants in a paddy and measuring them from root to the tip of the terminal bud.

3.6 Determination of depth of Water

At the same time the depths of water in the paddies was measured in both Mbui Njeru and Mathangauta study areas by holding a plastic ruler upright with the lower end touching at the bottom of the paddy. The depth was recorded once a month.

3.7 Data handling and Statistical analysis

All the data collected were processed, and coded where necessary and then fed into the computer. The data collected was analysed statistically using different tests to address particular aspects. During the analysis, counts from indoors were treated separately from those obtained outdoors.

Initially, all data collected by different methods in each village

was analysed collectively as described below to obtain an overall picture of the relative density of the vector mosquitoes. Data was in most cases normalised by $\log_{10}$ transformation prior to detailed analysis.

The following main statistical methods (Kirkwood, 1988) were used:

i) Analysis of variance (ANOVA) was carried out to compare differences in mosquito relative density obtained in different houses, villages and on different days of collection.

ii) t-tests were carried out to compare differences in mosquito counts between villages as collected by different methods such as:-

a) Hand collection

b) Pyrethrum spray catches

c) CDC light trap

ii) Analysis of variance (ANOVA) was also used to compare larval densities in paddies between and within the two study villages.

iii) The Chi-square test was used to compare proportions of different Physiological states of abdomen found in different situations (Indoors/Outdoors) for the same or different sampling techniques.

3.8 RESULTS

3.8.1 Mosquito Species diversity

Results on species composition in Mbui Njeru and Mathangauta

Table 1. Numbers (n) and percent (%) of Mosquito species collected in Mbui Njeru and Mathangauta by hand collection method from April 1989 to February 1991.

A. Mbui Njeru

Species	No. and % of mosquitoes					
	Indoors		Outdoors		Total	
	n	%	n	%	n	%
1. *An. arabiensis*	13450	82.4	1474	73.6	14924	81.4
2. *Cx. quinqs.*	2416	14.8	147	7.3	2563	13.98
3. *An. funestus*	299	1.8	66	3.3	365	1.99
4. *An. pharoensis*	115	0.7	69	3.4	184	1
5. *Cx. annulioris*	77		17		94	0.5
6. *An. rufipes*	44	0.3	234	11.7	278	1.5
7. *A. pretoriensis*	1	0.01	0	0	1	0.005
8. *A. maculipalpis*	5	0.03	13	0.6	18	0.098
9. *Cx. poicilipes*	0		3		3	0.02
Total	16407	100	2023	99.9	18430	99.97
B. Mathangauta						
1. *An. arabiensis*	2990	50.3	402	17.3	3032	38.4
2. *An. funestus*	2416	40.6	183	7.9	2599	32.9
3. *An. rufipes*	29	0.5	1352	58.3	1381	17.5
4. *Cx. quinqs.*	423	7.1	39	2	462	5.8
5. *Cx. annulioris*	42	0.7	6	0.3	48	0.6
6. *An. pharoensis*	25	0.4	178	8	203	2.5
7. *A. pretoriensis*	0	0	58	3	58	0.7
8. *A. maculipalpis*	18	0.3	86	4	104	1.3
9. *Cx. poicilipes*	0	0	14	0.6	14	0.2
10. *Mansonia* spp.	1	0.02	3	0.1	0	0
Total	5944	100	2321	102	7901	99.9

n = numbers
% = Percentage
quinqs.= *quinquefasciatus*

villages are summarized in table 1 and appendix 1. A total of nine mosquito species were recorded in Mbui Njeru while in Mathangauta there were 10 species. There was a variation in the number of different species of mosquitoes collected and their numbers differed in the two villages (Table 1). *An. arabiensis* and *An. funestus* both of them malaria vectors, were among the three most predominant species collected. Overall *An. arabiensis* was the predominant species in both Mbui Njeru (81.4%) and Mathangauta (38.4%) villages respectively. *Cx. quinquefasciatus*, a vector of *Wuchereria bancrofti* at the coastal area in Kenya was the second highest (13.98%) in Mbui Njeru and fourth (5.8%) in Mathangauta village. However, it is not considered important in this region. *An. funestus* accounted for 32.9% of all the mosquitoes in Mathangauta compared to only 1.99% in Mbui Njeru village. Another species considered as a potential vector of malaria *An. pharoensis* (1%) was also recorded. Other species collected were few. In Mbui Njeru the relative density of *An. rufipes* was extremely low indoors (0.3%) while more were recorded outdoors (11.7%). In Mathangauta *An. rufipes* was the predominant species collected outdoors accounting for 59% of all the species recorded.

The relative densities of the mosquitoes recorded throughout the year varied from species to species. Generally *An. arabiensis* was present throughout the year in both Mbui Njeru and Mathangauta villages. In Mathangauta, *An. arabiensis* and *An. funestus* densities varied such that when the numbers of *An. arabiensis* increased those of *An. funestus* decreased (Figures 3 and 3.1). The highest proportions of *An. arabiensis* were recorded in September in both

Figure 3. **Relative percentages (%) of different mosquito species collected in Mbui Njeru from April 1989 to February 1990.**

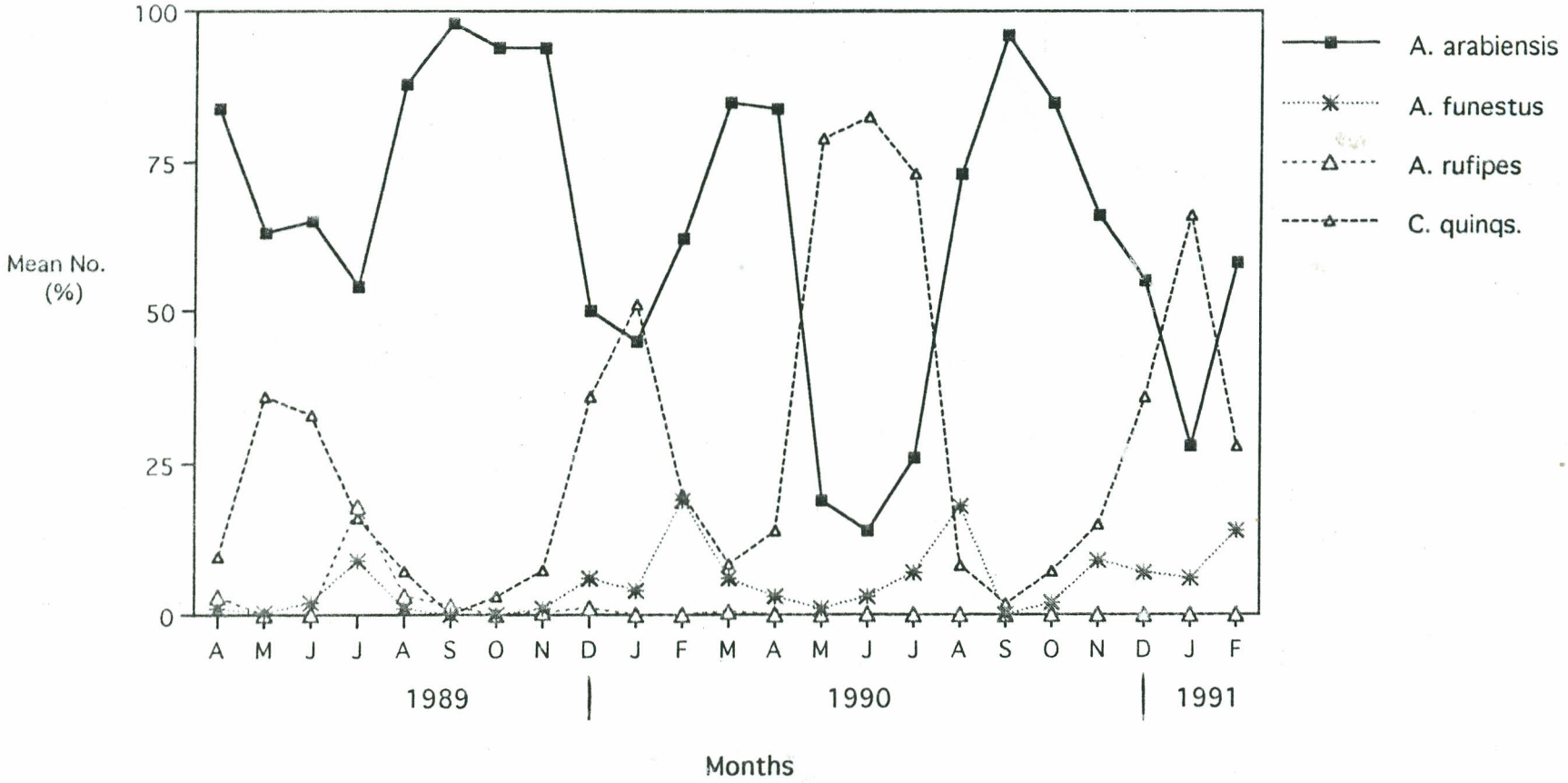
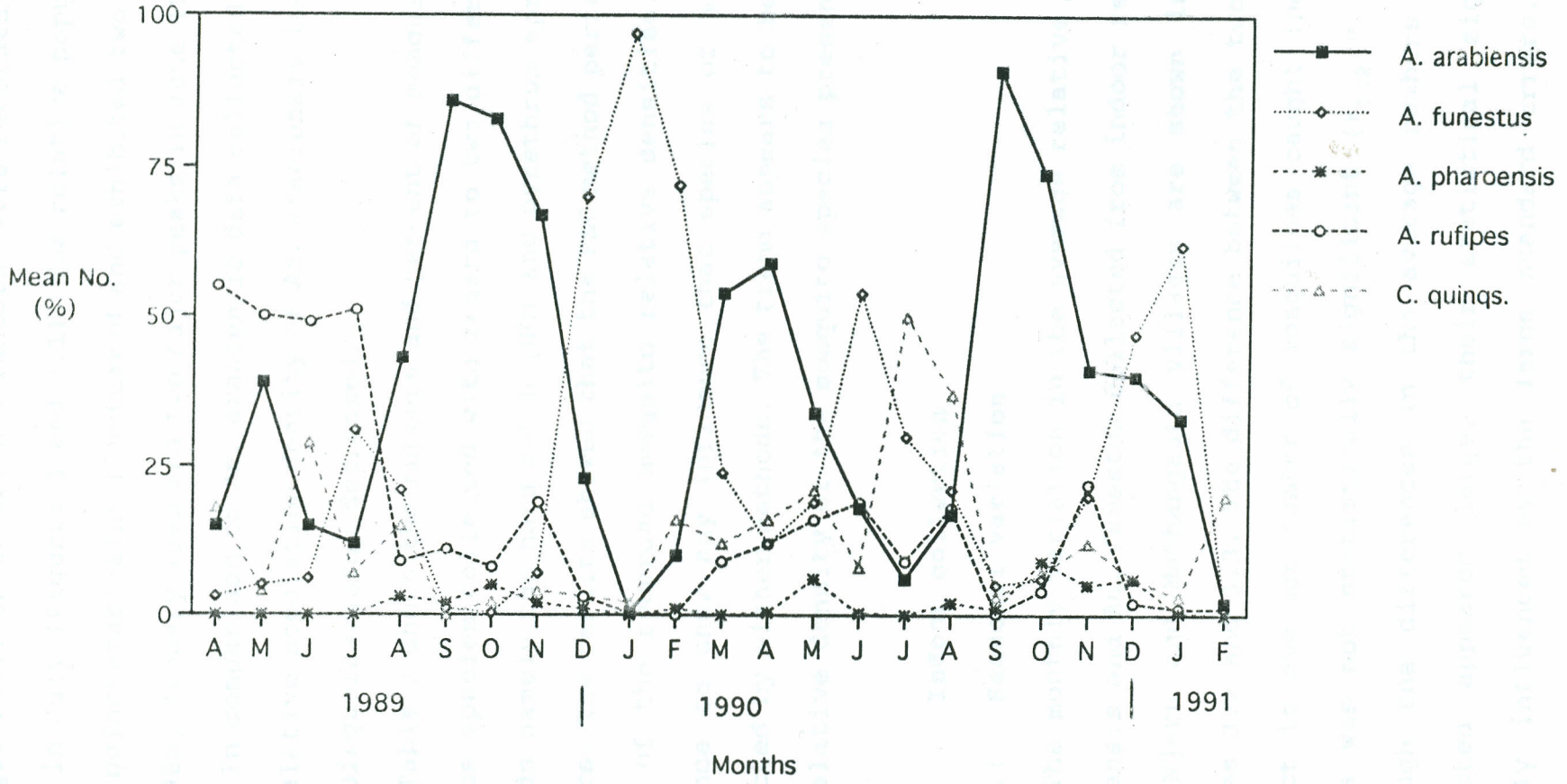

100
75
50
25
0
Mean No.
(%)
A. arabiensis
A. funestus
A. rufipes
C. quinqs.
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
Months

Figure 3.1. **Relative percentages (%) of different mosquito species composition collected in Mathangauta from April 1989 to February 1990.**


100
75
50
25
0
Mean No.
(%)
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
Months
A. arabiensis
A. funestus
A. pharoensis
A. rufipes
C. quinqs.

villages while those for *An. funestus* were recorded in January and again in July (Figures 3 and 3.1). The relative population density of *C. quinquefasciatus* fluctuated and exhibited two minor peaks in May 1989, January 1990 and two major peaks in June 1990 and January 1991. In comparison to *An. arabiensis* data collected showed that as the relative population density of *An. arabiensis* increased that of *Cx. quinquefasciatus* decreased.

Table 2 shows the numbers and percent of mosquitoes comparing various species collected with regard to two different collection methods namely the hand catch (HC) and pyrethrum spray catch (PSC) indoors. The results showed that the PSC method performed better in terms of the recorded mosquito relative densities. There was no evidence to show any influence that species of mosquitoes were collected by either methods. The trend appears to be determined by the relative density of the mosquito species present.

3.8.2 Indoor collection

3.8.2.1 Seasonal variation

The monthly variation in the average relative numbers of *An. arabiensis* and *An. funestus* collected from indoor resting sites in Mbui Njeru and Mathangauta villages are shown in table 3 and figures 3.2 and 3.3. The difference between the two villages with respect to average number of mosquitoes caught indoors from the houses was not statistically significant ($F_{1,22} = 3.06$; $P>0.05$). Although the differences in the average numbers of mosquitoes collected appeared large, their statistical significance was greatly influenced by the large standard errors. However, the

Table 2. Numbers (n) and Percent (%) of Mosquito species collected in Mbui Njeru and Mathangauta villages by hand and Pyrethrum spray catch methods from February 1990 to February 1991.

A Mbui Njeru

Mosquito Species	No. and % HC In n	%	PSC In n	%	Total n	%
An. arabiensis	2317	67.5	15861	89.5	18178	85.9
An. funestus	179	5.2	196	1.1	375	1.8
C. quinqs.	851	24.8	1646	9.3	2497	11.8
An. rufipes	3	0.1	0	0	3	0.01
An. pharoensis	70	2.0	18	0.1	88	0.4
An. pretoriensis	1	0.03	0	0	1	0.004
C. annulioris	11	0.3	4	2.3	15	0.071
Total	3432	101.6	17,725	102	21157	99.9

B Mathangauta

Species	HC In n	%	PSC In n	%	Total n	%
An. arabiensis	892	41.3	12337	91.6	13229	84.7
An. funestus	1026	47.5	828	6.1	1854	11.9
An. rufipes	24	1.1	2	0.01	26	0.2
C. quinqs.	196	43.6	254	1.9	450	2.9
An. maculipalpis	18	0.8	0	0	18	0.1
An. pharoensis	2	0.09	30	0.2	32	0.2
C. annulioris	1	0.05	13	0.1	14	0.1
Total	2159	99.9	13,464	99.9	15,623	

In = Indoors
Out = Outdoors
n = Number of mosquitoes collected
% = Percent of all collection
HC = Hand Catch collection
PSC = Pyrethrum Spray Catch method

Table 3. Numbers (n) of *An. arabiensis* and *An. funestus* collected indoors in Mbui Njeru and Mathangauta villages.

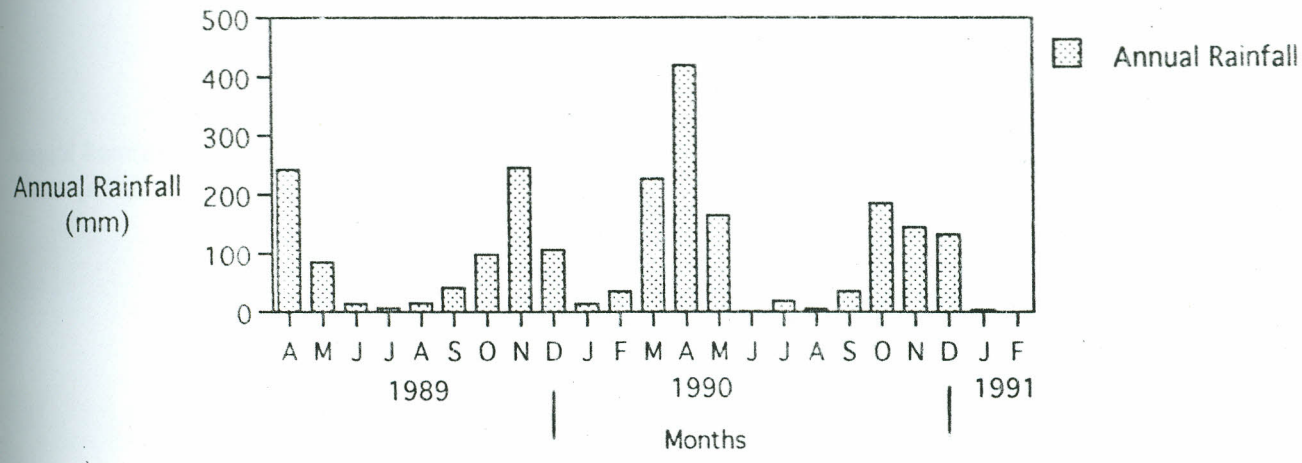
Village	Species	n	Total	Mean/House
Mbui Njeru	*An. arabiensis*	23	30857	1341
	An. funestus	23	664	30
Mathangauta	*An. arabiensis*	23	9374	408
	An. funestus	23	4332	188

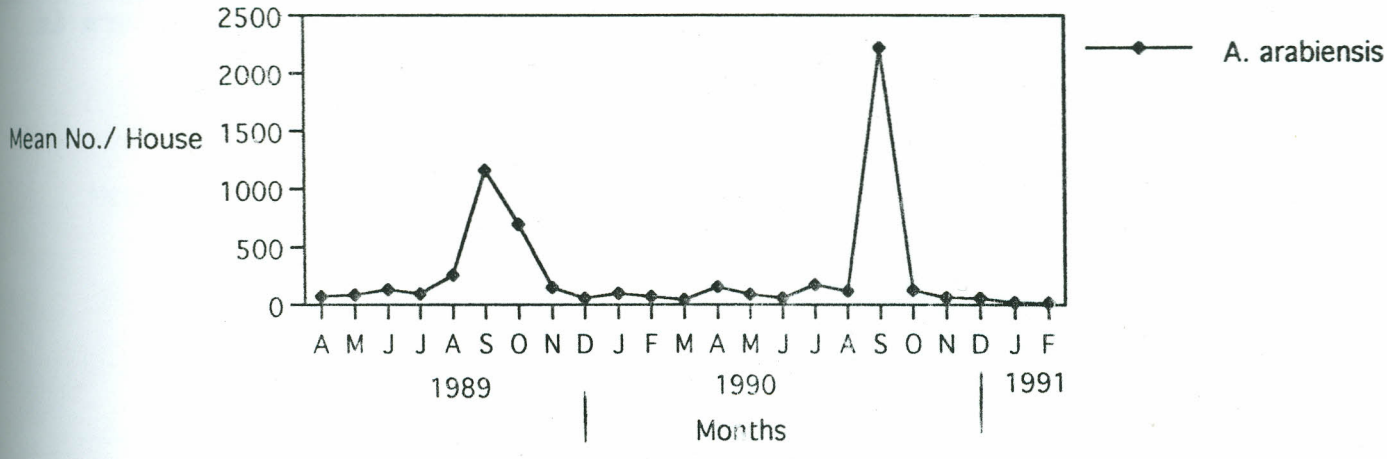
Table 3a. ANOVA table on the catches of *An. arabiensis* and *An. funestus* collected indoors.

Sources of variation	SS	df	MSS	F	Sig.
Main Plot analysis					
Village	1352277	1	1352277	3.06	NS
Month	35203115	22	1600141	3.62	**
Error (a)	9714044	22	4414547		
Sub-Plot analysis					
Sex	1363151	1	1363151	29.70	***
Month X Sex	3377592	22	153526	3.38	**
Error (b)	1000635	22	45483		
Sub-sub plot analysis					
Species	5670756	1	5670756	52.5	***
Month X Species	34479780	22	1567262	14.5	***
Month XSex XSpecies	476751	22	216711	2.01	*
Error (c)	5073901	47	107955		
Total	110815205	183			

n = number of times collections were made
* = Significant (P<0.05)
** = Highly Significant (P<0.01)
SS = Sum of Squares
df = Degrees of freedom
MSS = Mean Sums of Squares
F = Variance ratio
Sig. = Significance
NS = Not significant (P > 0.05)

Figure 3.2. **Monthly variation in rainfall and numbers of *An. arabiensis*, *An. funestus* collected indoors i Mbui Njeru village.**


Annual Rainfall
(mm)
500
400
300
200
100
0
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
Months
Annual Rainfall


Mean No./ House
2500
2000
1500
1000
500
0
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
Months
A. arabiensis

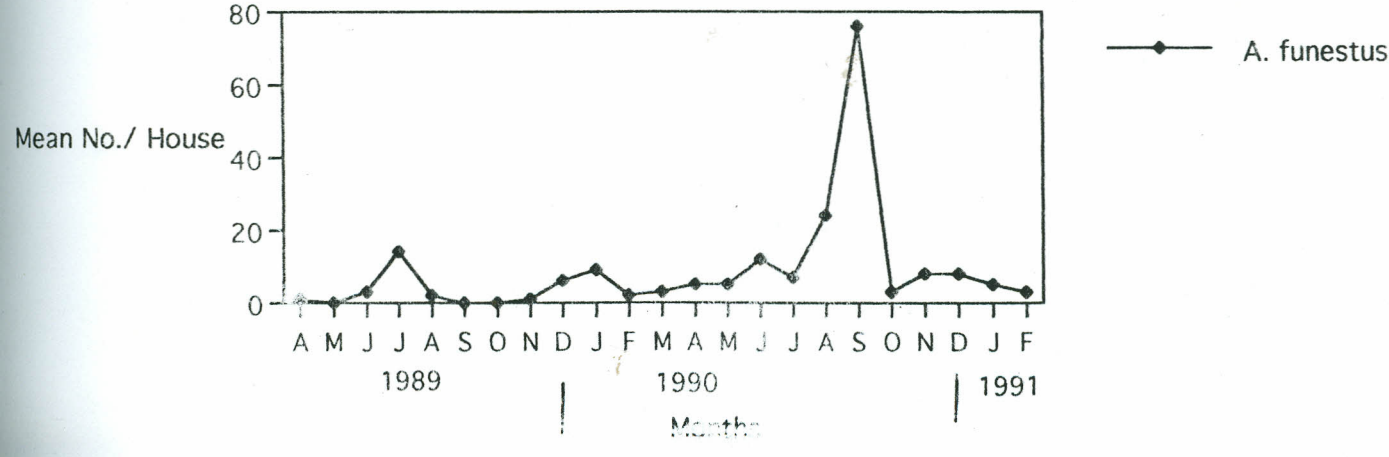
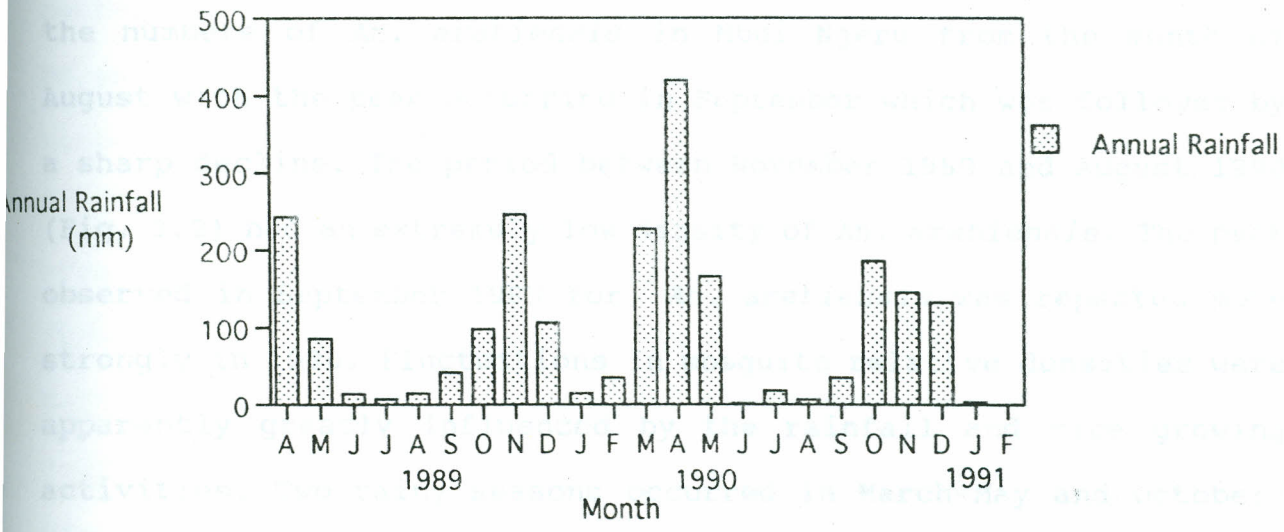
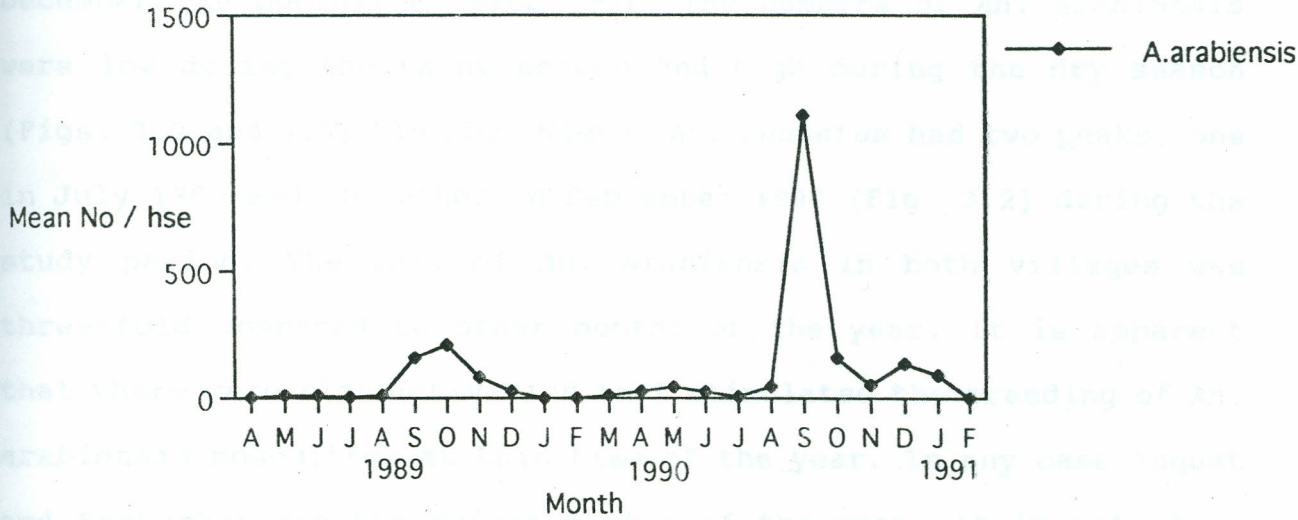
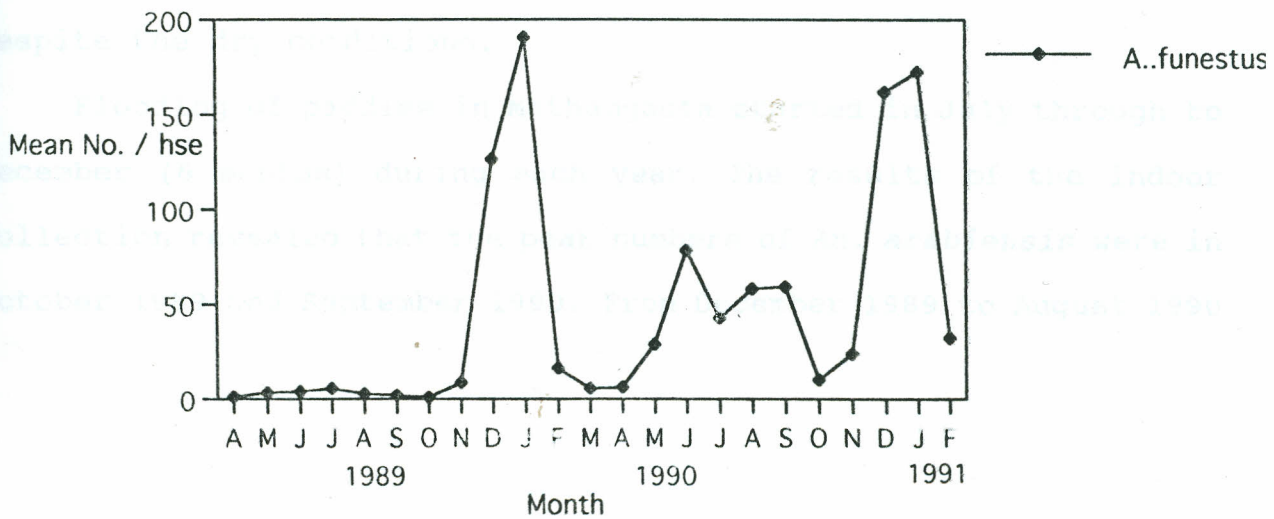

Mean No./ House
80
60
40
20
0
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
A. funestus

Figure 3.3. **Monthly variation in rainfall and numbers of *An. arabiensis*, *An. funestus* collected indoors in Mathangauta village.**


Annual Rainfall (mm)
500
400
300
200
100
0
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
Month
Annual Rainfall


Mean No / hse
1500
1000
500
0
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
Month
A.arabiensis


Mean No. / hse
200
150
100
50
0
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
Month
A..funestus

numbers caught differed significantly between the months, with September generally having higher numbers than other months ($F_{22,22}$ = 3.62; P<0.01) (Fig. 3.2). In 1989 there was a gradual increase in the numbers of *An. arabiensis* in Mbui Njeru from the month of August with the peak occurring in September which was followed by a sharp decline. The period between November 1989 and August 1990 (Fig. 3.2) had an extremely low density of *An. arabiensis*. The peak observed in September 1989 for *An. arabiensis* was repeated more strongly in 1990. Fluctuations in mosquito relative densities were apparently greatly influenced by the rainfall and rice growing activities. Two rainy seasons occurred in March-May and October-December. Flooding of paddies started from March through to December (10 months) of each year. The numbers of *An. arabiensis* were low during the rainy season and high during the dry season (Figs. 3.2 and 3.3). In Mbui Njeru, *An. funestus* had two peaks, one in July 1989 and the other in September 1990 (Fig. 3.2) during the study period. The peak of *An. arabiensis* in both villages was three-fold compared to other months of the year. It is apparent that there were rice activities that stimulated the breeding of *An. arabiensis* mosquitoes at this time of the year. In any case August and September are the driest months of the year. It is not clear why the peak number of *An. arabiensis* was experienced in September despite the dry conditions.

Flooding of paddies in Mathangauta started in July through to December (6 months) during each year. The results of the indoor collection revealed that the peak numbers of *An. arabiensis* were in October 1989 and September 1990. From December 1989 to August 1990

the numbers of *An. arabiensis* were very low. Similarly, *An. funestus* was in its lowest numbers from April-Nov, 1989. The peak numbers of *An. funestus* occurred in December 1989, January and December 1990 and January 1991. From April to November 1990 the numbers were consistently low.

It should be noted that of the two malaria vectors in the area, *An. arabiensis* were significantly more abundant than *An. funestus* ($F_{1,22}$ = 29.06; P<0.001) in Mbui Njeru village. However, in Mathangauta village, the situation was different. Although the average relative numbers of *An. arabiensis* were also significantly higher than *An. funestus* ($F_{22,22}$ = 8.03; P<0.01) in Mathangauta, there was evidence to show that when *An. funestus* species were found in large numbers, *An. arabiensis* were few. The peak numbers for *An. arabiensis* occurred in September and for *An. funestus* occurred in January and both were during the dry season (Fig. 3.4). Similar trend occurred in the sexes whereby more females than males were recovered during the dry season. Table 3.1 shows that overall, female *An. arabiensis* were significantly more than males ($F_{1,22}$ = 29.70; P<0.001).

3.8.3 Outdoor collection

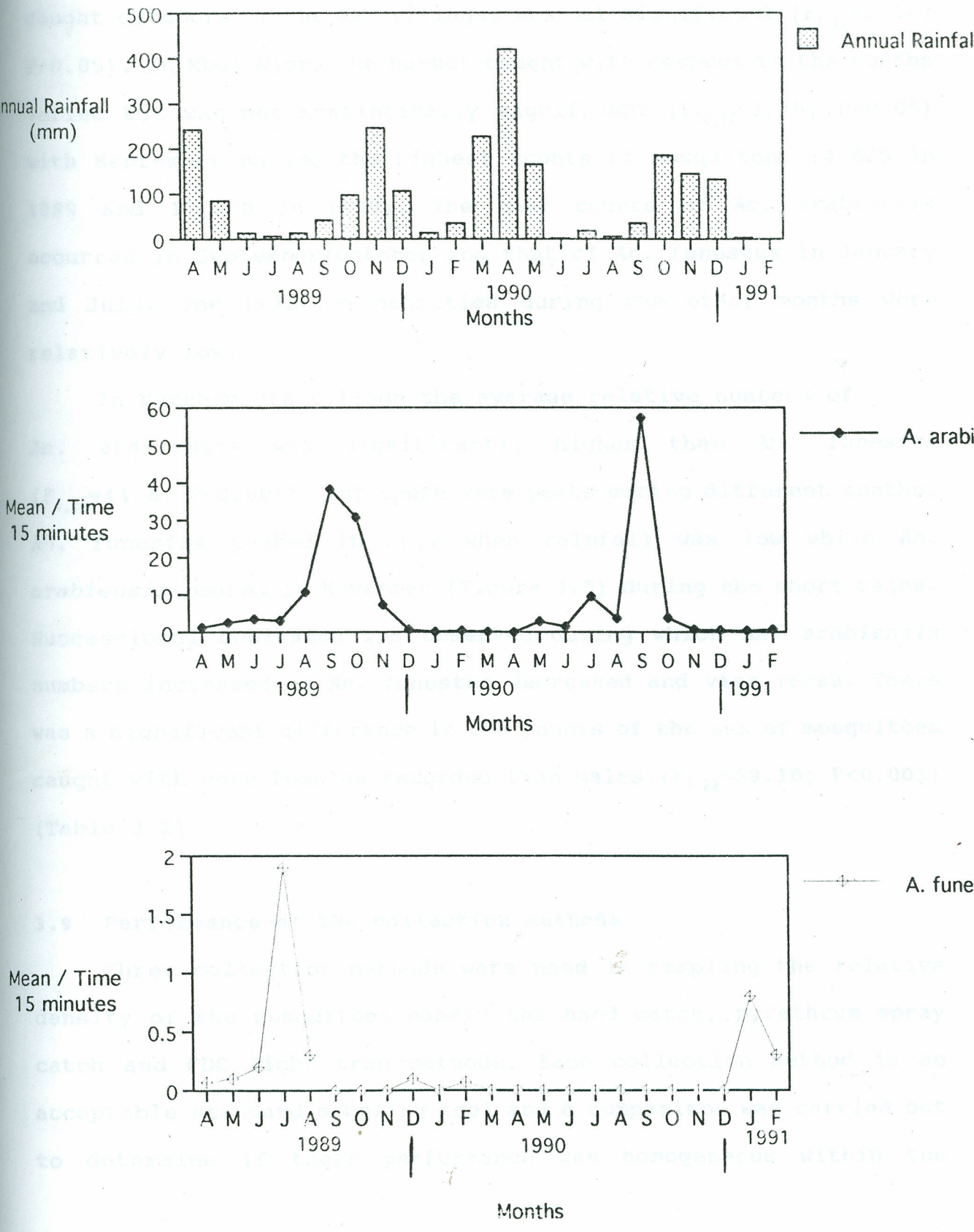
Results of the monthly variation in the relative numbers of mosquitoes collected outdoors are illustrated in figures 3.4 and 3.5. The average numbers of *An. arabiensis* was higher in both Mbui Njeru (73.6%) and Mathangauta (17.3%) than that of *An. funestus*. *An. rufipes* was prominent among the mosquitoes collected outdoors in Mbui Njeru (11.7%) and Mathangauta (58.3%) (Table 1). The

Table 3.1. **Distribution of female and male *An. arabiensis* and *An. funestus* in Mbui Njeru and Mathangauta villages.**

		An arabiensis				*An. funestus*			
		Indoors		Outdoors		Indoors		Outdoors	
		n	%	n	%	n	%	n	%
Mbui Njeru									
	F	19,079	67.6	1700	63.1	467	73.2	48	82
	M	9,126	32.4	994	36.9	171	26.8	10	18
Total		28,205	100	2694	100	638	100	58	100
Mathangauta									
	F	6091	68.4	283	60.9	3239	77.7	108	65.5
	M	2818	31.6	182	39.1	928	22.3	57	34.5
Total		8909	100	465	100	4167	100	165	100

% = Proportion of Males and Females
n = Number of mosquitoes
F = Females
M = Males

Figure 3.4. **Seasonal variation in rainfall and numbers of *An. arabiensis*, *An. funestus* collected outdoors in Mbui Njeru.**


nnual Rainfall (mm)
500
400
300
200
100
0
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
Months
Annual Rainfal
Mean / Time 15 minutes
60
50
40
30
20
10
0
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
Months
A. arabi
Mean / Time 15 minutes
2
1.5
1
0.5
0
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
Months
A. fune

results of the statistical analysis of variance are shown in tables 3.3 and 3.3a. The difference between the numbers of mosquitoes caught outdoors in the two villages was not significant ($F_{1,22}$=2.16; P>0.05). In Mbui Njeru the number caught with respect to the months varied but was not statistically significant ($F_{22,22}$=1.58; P>0.05) with September having the highest counts of mosquitoes (4,625 in 1989 and 12,700 in 1990). The peak counts of *An. arabiensis* occurred in September/October and that of *An. funestus* in January and July. The relative densities during the other months were relatively low.

In Mathangauta village the average relative numbers of *An. arabiensis* was significantly higher than *An. funestus* ($F_{1,22}$=44.6; P<0.001), but there were peaks during different months. *An. funestus* peaked in July when rainfall was low while *An. arabiensis* peaked in November (Figure 3.5) during the short rains. Successional dominance was observed during which *An. arabiensis* numbers increased as *An. funestus* decreased and vice versa. There was a significant difference in the counts of the sex of mosquitoes caught with more females recorded than males ($F_{1,22}$=59.10; P<0.001) (Table 3.2).

3.9 Performance of the collection methods

Three collection methods were used in sampling the relative density of the mosquitoes namely the hand catch, pyrethrum spray catch and CDC light trap methods. Each collection method is an acceptable standard sampling tool and a comparison was carried out to determine if their performance was homogeneous within the

Table 3.2. Monthly numbers of *An. arabiensis* and *An. funestus* per house collected outdoors in Mbui Njeru and Mathangauta villages.

Village	Species	n	Total	Mean/15 min.
Mbui Njeru	*An. arabiensis*	23	1474	64.1
	An. funestus	23	183	7.9
Mathangauta	*An. arabiensis*	23	401	17.4
	An. funestus	23	190	8.3

Table 3.2a. ANOVA table on the numbers of *An. arabiensis* and *An. funestus* collected outdoors in Mbui Njeru and Mathangauta villages.

Sources of variation	SS	df	MSS	F-value	Sig.
Main Plot Analysis					
Village	0.93	1	0.927	2.16	NS
Month	14.89	22	0.677	1.58	NS
Error (a)	9.46	22	0.430		
Sub-Plot Analysis					
Sex	2.955	1	2.955	59.10	*
Month X Sex	1.80	22	0.082	1.64	NS
Error (b)	1.11	22	0.050		
Sub-Sub Plot Analysis					
Species	17.463	1	17.463	44.60	***
Month X Species	16.375	22	0.744	0.53	NS
Month XSex XSpecies	131.64	22	5.984	15.35	***
Error (c)	18.42	47	0.392		
Total	83.96	183			

n = Number of months collections were made
SS = Sum of squares
df = degrees of freedom
MSS = Mean sum of squares
Sig.= Significance
NS = Not significant (P>0.01)
* = Significant (P<0.01)
** = Highly significant (P<0.001)

Table 3.3. **Numbers of *An. arabiensis* and *An. funestus* species obtained by hand and pyrethrum spray catch methods.**

A. Mbui Njeru

	n	Mean/Hse	SS	Z-value	Sig.
An. arabiensis					
Pyrethrum S.C.	13	1200	3568	-0.00103	**
Hand catch	13	178	342		
An. funestus					
Pyrethrum S.C.	13	15	24	-0.14	NS
Hand catch	13	14	9		

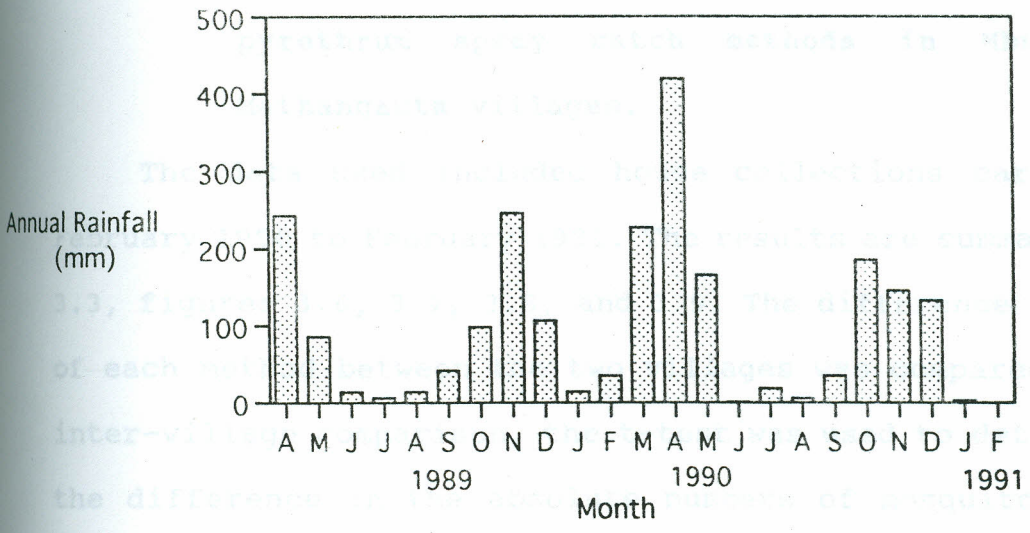
Mean = Mean number of mosquitoes per house
n = Number of times of collection
S = Sum of Squares
Z = Normal distribution value
Sig. = Significance
NS = Not significant
* = Significant
** = Highly significant

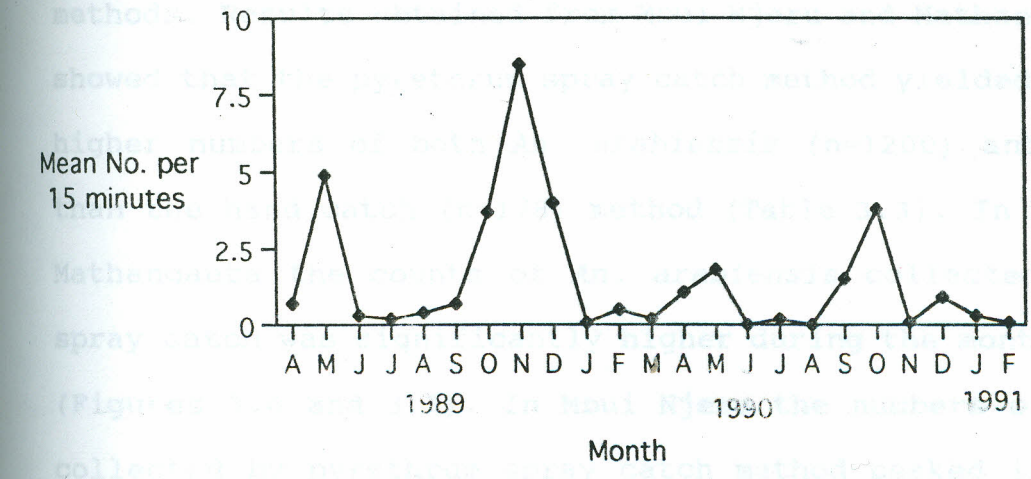
methods were identified to various species and recorded accordingly.

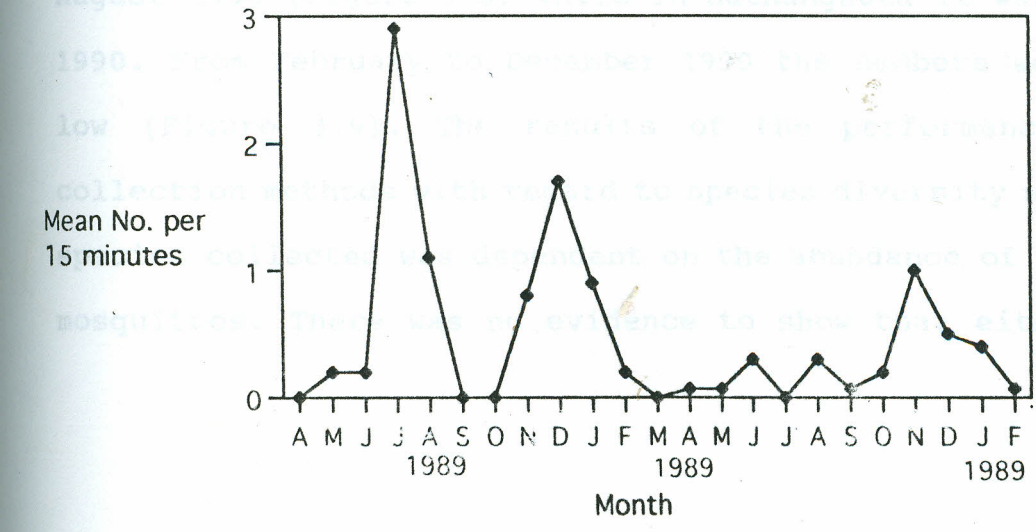
The physiological status of females of the two commonly known malaria vector species namely, *Anopheles arabiensis* and *Anopheles funestus*, was determined on the basis of abdominal appearance. Salivary glands and midguts of individual mosquitoes from the two species were also dissected out and examined for malaria parasites in the sporozoite and oocyst stages, respectively. Gut contents of the fully fed females were also individually collected on filter paper for blood meal analysis. Parallel to observations on mosquito infections, samples of finger prick blood smears from the human population were also made to determine the malaria parasite prevalence.

A total of ten mosquito species which included *An. arabiensis* and *An. funestus*, the two known vectors of malaria were recorded from the study area. *An. pharoensis* which is suspected to have some potential role for malaria transmission was among the species collected. *An. rufipes* was the predominant species among those collected from outdoor resting sites. Monthly numbers of mosquitoes were significantly different with a definite peak recorded during the month of September. From the results obtained in this study it was evident that the fluctuation patterns of the vector mosquito numbers was greatly influenced by the rice growing cycle. The onset of preparation for rice nurseries particularly encouraged larval breeding. During harvesting period when water was drained from the

Figure 3.5. **Seasonal variation in rainfall and number of *An. arabiensis* and *An. funestus* collected outdoors in Mathangauta village.**


500
400
300
200
100
0
Annual Rainfall
(mm)
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
Month
Annual Rainfall


10
7.5
5
2.5
0
Mean No. per
15 minutes
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
Month
An. arabiens

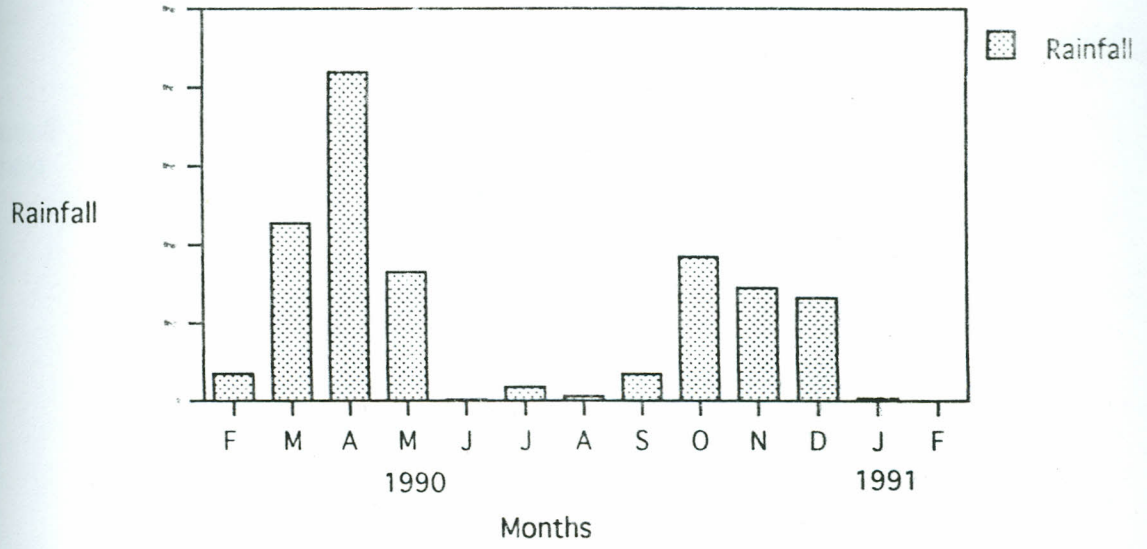

3
2
1
0
Mean No. per
15 minutes
A M J J A S O N D J F M A M J J A S O N D J F
1989
1989
1989
Month
An. funestu

villages and also in regard to species diversity.

3.9.1. Comparison of the monthly numbers of *An. arabiensis* and *An. funestus* simultaneously obtained by hand and pyrethrum spray catch methods in Mbui Njeru and Mathangauta villages.

The data used included house collections carried out from February 1990 to February 1991. The results are summarized in table 3.3, figures 3.6, 3.7, 3.8, and 3.9. The difference in performance of each method between the two villages was compared. Besides the inter-village comparison, the t-test was used to determine whether the difference in the absolute numbers of mosquitoes in a house were significant when estimated by spray catch and hand collection methods. Results obtained from Mbui Njeru and Mathangauta villages showed that the pyrethrum spray catch method yielded significantly higher numbers of both *An. arabiensis* (n=1200) and *An. funestus* than the hand catch (n=178) method (Table 3.3). In Mbui Njeru and Mathangauta the counts of *An. arabiensis* collected by pyrethrum spray catch was significantly higher during the month of September (Figures 3.6 and 3.7). In Mbui Njeru the numbers of *An. funestus* collected by pyrethrum spray catch method peaked in February and August 1990 (Figure 3.8) while in Mathangauta it was in September 1990. From February to December 1990 the numbers were relatively low (Figure 3.9). The results of the performance of the two collection methods with regard to species diversity showed that the species collected was dependent on the abundance of the respective mosquitoes. There was no evidence to show that either collection

Figure 3.6. **Seasonal numbers of *An. arabiensis* in Mbui Njeru village collected using hand and pyrethrum spray catch methods.**


Rainfall
Rainfall
F M A M J J A S O N D J F
1990
1991
Months

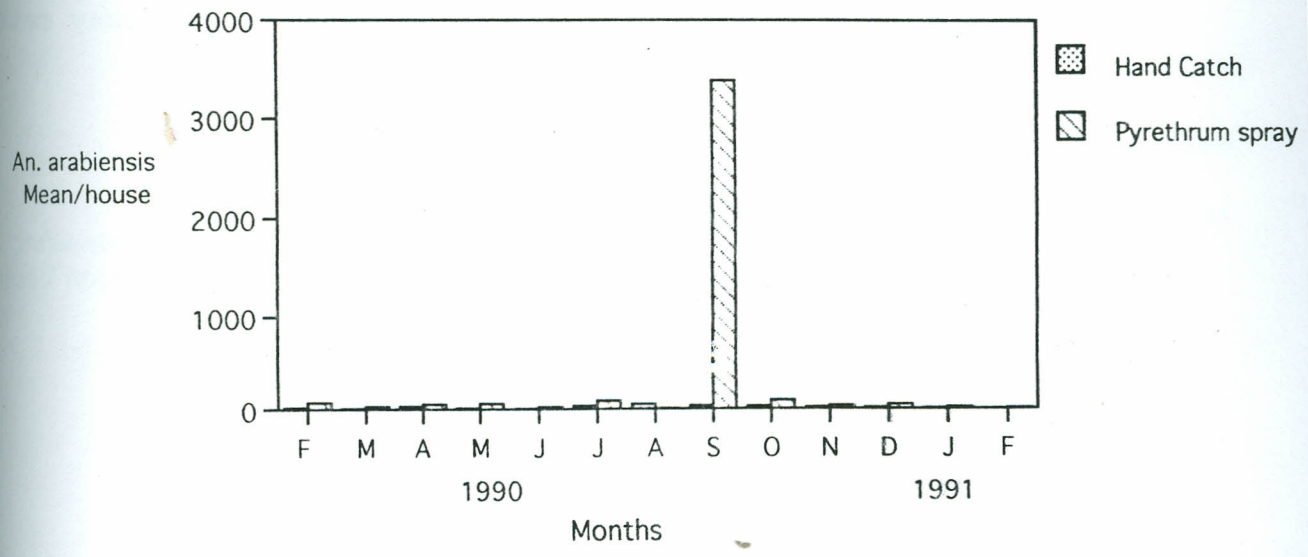
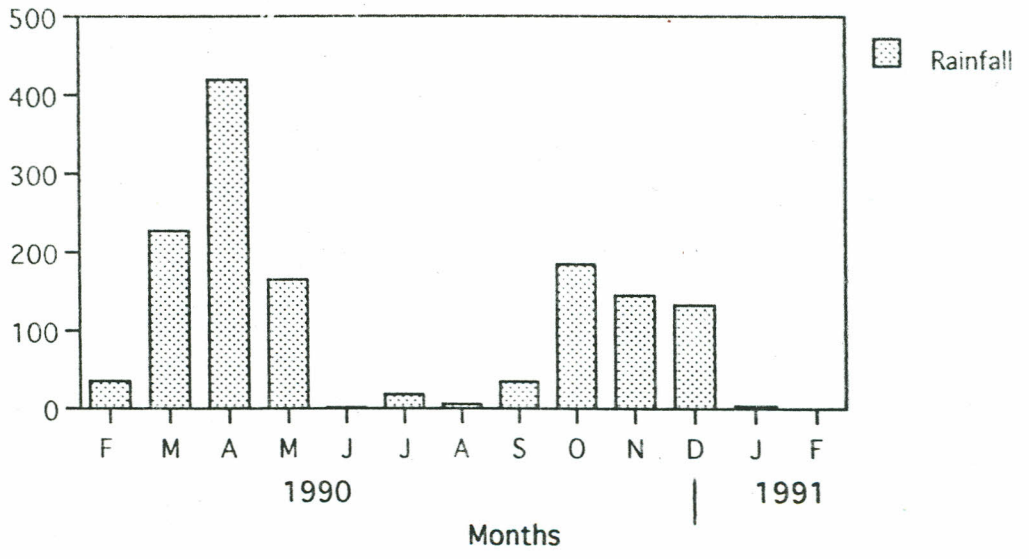
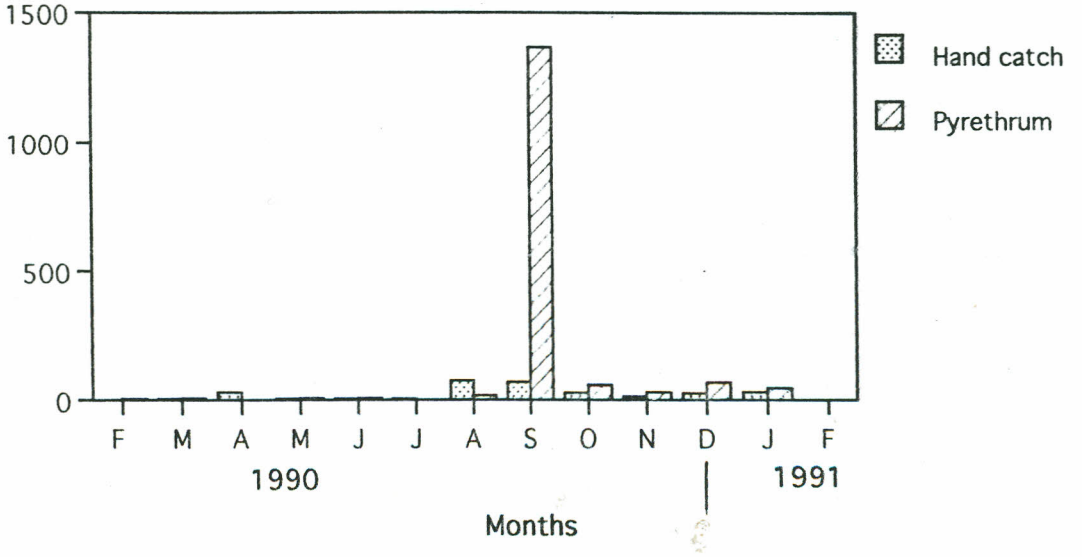

An. arabiensis
Mean/house
4000
3000
2000
1000
0
Hand Catch
Pyrethrum spray
F M A M J J A S O N D J F
1990
1991
Months

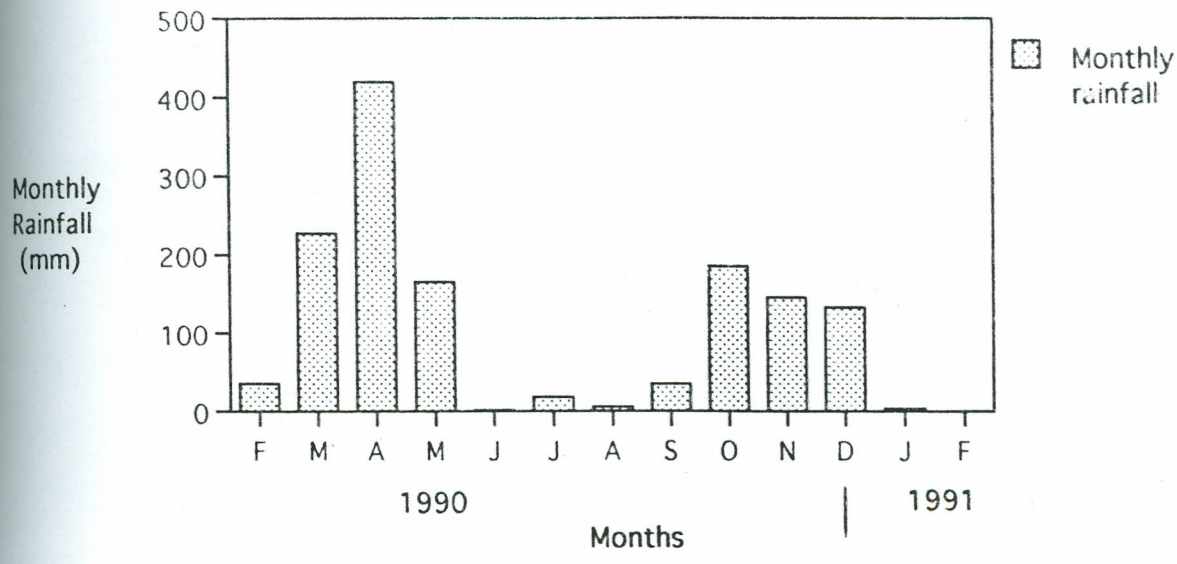
Figure 3.7. **Seasonal counts of *An. arabiensis* in Mathangauta village using hand catch and pyrethrum spray catch methods.**

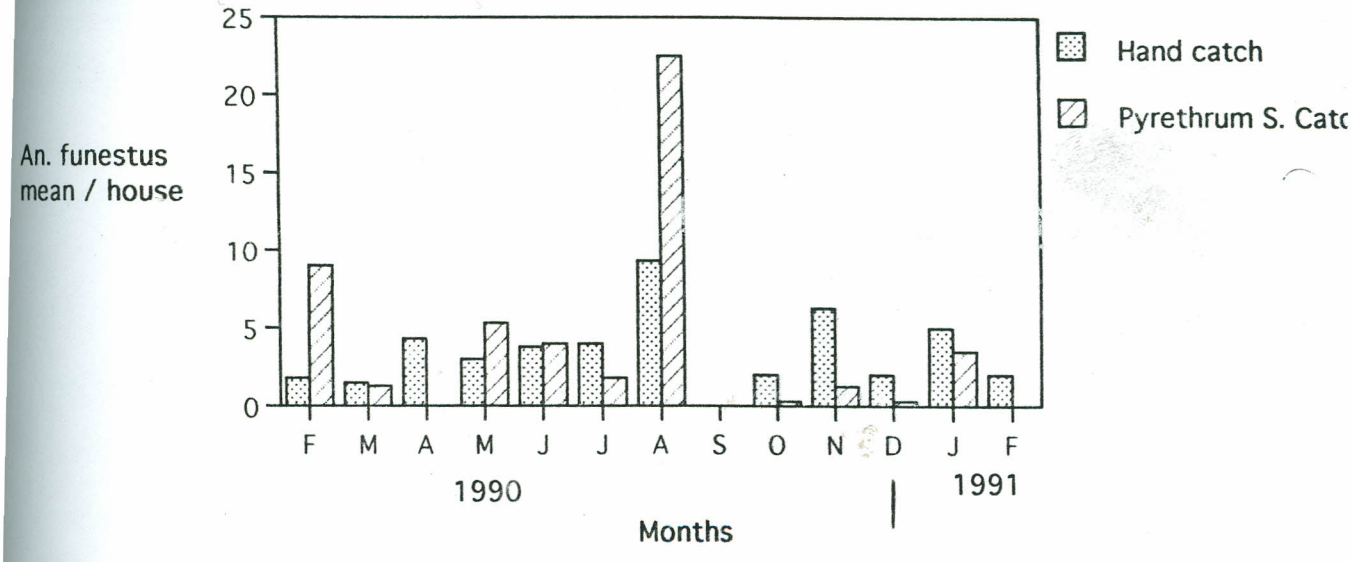




. arabiensis
ean / house

Figure 3.8. **Seasonal counts of *An. funestus* in Mbui Njeru village collected using hand and pyrethrum spray catch methods.**


Monthly Rainfall (mm)
500
400
300
200
100
0
F M A M J J A S O N D J F
1990
1991
Months
Monthly rainfall


An. funestus mean / house
25
20
15
10
5
0
F M A M J J A S O N D J F
1990
1991
Months
Hand catch
Pyrethrum S. Catc

method favoured one mosquito species more than the other.

3.9.2 Variations in the relative density of mosquitoes in relation to rice growing activities in Mbui Njeru.

Results on Seasonal variation show that the mean numbers of *An. arabiensis* collected by the pyrethrum spray catch method were significantly higher during the dry season than the wet season (Table 3.4). Observations of the numbers at different stages of rice growing activities showed that the mean number of *An. arabiensis* was significantly higher when paddies were flooded ($\bar{X}$= 1523) than when they were dry ($\bar{X}$=122.7) for both hand collection and pyrethrum spray catches. Observations on *An. funestus* show that the mean numbers during the dry season compared to the dry season was not statistically significant for both hand catch and pyrethrum spray catch methods. The monthly mean numbers observed for *An. funestus* when paddies were flooded compared to when the paddies were dry was not statistically significant ($P<0.01$).

3.9.3 Variations in the relative density of mosquitoes in relation to rice growing activities in Mathangauta.

Results on seasonal variation in numbers of *An. arabiensis* in Mathangauta village collected by hand catch and pyrethrum spray catch methods show that the mean numbers for *An. arabiensis* during the dry season was significantly higher than the wet season and also when paddies were flooded than when they were dry for both methods (Table 3.5). The mean number of *An. funestus* was significantly higher during the dry season than the wet season but

Table 3.4. **Seasonal numbers of *An. arabiensis* and *An. funestus* in Mbui Njeru collected by hand and pyrethrum spray catch methods during different times of rice growing activities.**

A. *An. arabiensis*

	Season				
Method	Dry Mean	Wet Mean	t-value	P-value	Sig.
P.S.C.	2054.57	202.67	2.806	0.005	**
H.C.	266	75.8	7.259	0.0005	**
t-value	0.929	3.336			
P-value	2.179	2.228			
Sig.	*	*			
df	12	10			

	Paddy condition				
Method	Dry	Flooded			
P.S.C.	122.7	1523.0	-1.757	0.06	**
H.C.	46	217.9	-0.682	0.25	**
t-value	-1.006	-0.972			
P-value	-2.776	-2.101			
Sig.	*	**			
df	4	18			

B. *An. funestus*

	Season				
Method	Dry	Wet	t-value	P-value	Sig.
P.S.C.	23.3	5.5	1.328	0.10	NS
H.C.	14.7	12.7	0.357	0.30	NS
t-value	-0.668	1.65			
P-value	-2.179	2.228			
Sig.	*	*			

	Paddy condition				
Method	Dry	Flooded			
P.S.C.	16.7	14.6	0.123	0.25	NS
H.C.	11.7	14.4	-0.4091	0.30	NS
t-value	-0.443	-0.022			
P-value	-2.776	-2.101			
Sig.	NS	NS			

P.S.C. = Pyrethrum spray catch
H.C. = Hand catch
t = T-test value
P = Probability
Sig. = Significance
* = Significant (P=0.05)
Dry = Season without rainfall
Wet = Season with rainfall
df = Degrees of freedom
NS = Not significant
** = Highly significant(P=0.05)

Table 3.5. **Seasonal numbers of *An. arabiensis* and *An. funestus* in Mathangauta village collected by hand and pyrethrum spray catch methods during different times of rice growing activities.**

A. *An. arabiensis*					
	Season				
Method	Dry Mean	Wet Mean	t-value	P-value	Sig.
P.S.C.	822.4	108.8	0.847	0.20	**
H.C.	105.7	69.2	0.65	0.12	**
t-value	-0.924	-0.784			
P-value	-2.179	-2.228			
Sig.	**	*			
df	12	10			
	Paddy condition				
P.S.C.	37.71	1024.3	-0.00145	0.25	NS
H.C.	43.40	141.8	-2.007	0.10	**
t-value	0.184	-0.992			
P-value	2.179	-2.228			
Sig.	NS	**			
df	12	10			
B. *An. funestus*					
	Season				
Method	Dry	Wet			
P.S.C.	96.4	25.8	1.538	0.07	NS
H.C.	117.6	33.8	1.073	0.25	*
t-value	0.261	0.361			
P-value	2.179	2.228			
Sig.	NS	NS			
	Paddy condition				
	Dry	Flooded			
P.S.C.	64.3	63.3	0.0198	0.12	NS
H.C.	106.6	46.7	0.749	0.25	**
t-value	0.496	-0.71			
P-value	2.179	-2.228			
Sig.	NS	NS			

P.S.C. = Pyrethrum spray catch
H.C. = Hand catch
P = Probability
Sig. = Significance
* = Significant (P=0.05)
** = Highly Significant (P=0.05)
NS = Not Significant
df = Degrees of freedom

higher when paddies were dry compared to when they were flooded for both collection methods.

3.9.4 Comparison of monthly numbers of *An. arabiensis* and *An. funestus* species obtained by CDC light traps in Mbui Njeru and Mathangauta villages.

The results on the investigations on the mosquito vectors of malaria collected using the CDC light trap are summarized in table 3.6 and figures 3.10 and 3.11. The data show that the mean counts for *An. arabiensis* was significantly higher during the dry season and when the paddies were flooded (September 1990) than in the wet season (March to May 1990) and when paddies were dry (January 1990) respectively in both Mathangauta and Mbui Njeru villages. The peak density of *An. funestus* in Mbui Njeru and Mathangauta occurred during different months. In Mathangauta the numbers of *An. funestus* were highest in the month of December 1990 and also in January 1991 (Figure 3.11).

3.9.5 Numbers of *An. arabiensis* species obtained in Mbui Njeru village by hand and pyrethrum Spray catch methods in different houses.

The results of the numbers of *An. arabiensis* and *An. funestus* collected from the specific houses and the distance of the houses from the nearest paddy are shown in table 3.7 and figure 3.12.

The data show that in Mbui Njeru village the mean counts for houses numbers 1 and 3 had consistently high number of *An. arabiensis* mosquitoes 407 and 436 respectively than the other

Table 3.6. **Seasonal numbers of *An. arabiensis* in Mbui Njeru and Mathangauta villages collected by CDC light trap during different times of rice growing activities.**

A. *An. arabiensis*

Method	village	Season: Wet	Season: Dry	t-value	P-value	Sig.
CDC	MN	84.3	208.0	-0.945	-2.201	**(P=0.025)
"	M	59.7	120.8	-0.705	-3.106	** (P=0.05)
	t-value	0.7	0.617			
	P-value	0.7	0.694			
	Sig.	* (P=0.5)	NS (P>0.5)			
		Paddy				
		Flooded	Dry			
CDC	MN	184.1	40.3	0.927	2.201	** (P=0.025
"	M	159.5	18	2.018	1.796	** (P>0.10)
	t-value	0.202	1.202			
	P-value	0.692	1.398			
	Sig.	NS P>0.5	NS P>0.5			

CDC = CDC light trap.
MN = Mbui Njeru
M = Mathangauta
t-value = T-Test
P-value = Probability
Sig. = Significance
** = Highly Significant

Table 3.7. Numbers of *An. arabiensis* collected from the different houses in Mbui Njeru and Mathangauta villages

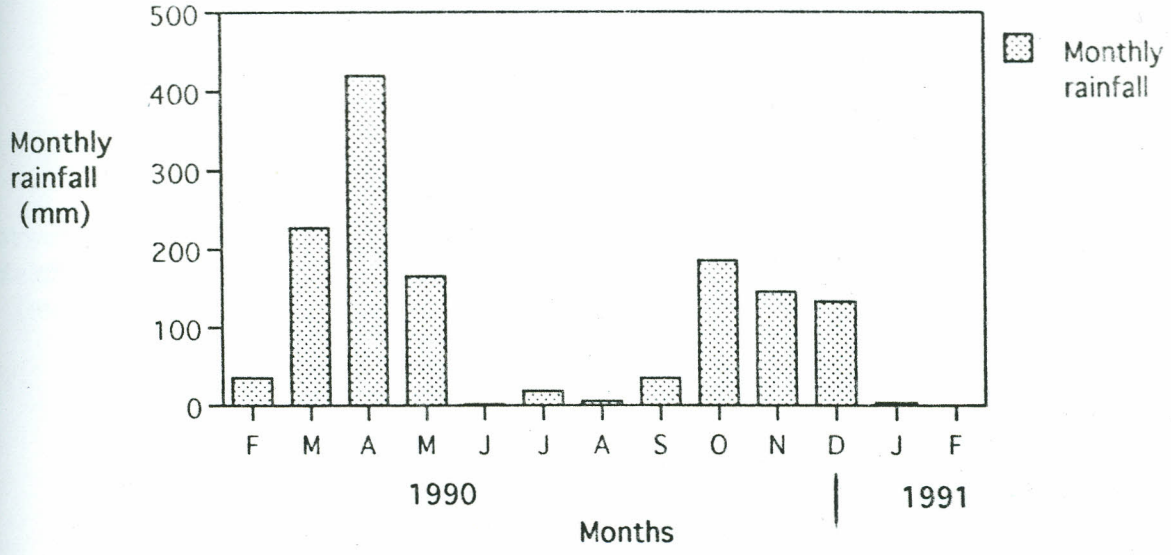
	Mbui Njeru				Mathangauta			
	House number							
	1	2	3	4	1	2	3	4
Total	2846	2073	3055	2618	829	236	200	410
Mean	407	296	436	374	118	33	29	59

Table 3.7a ANOVA showing the monthly numbers of *An. arabiensis* from four houses in Mbui Njeru and Mathangauta villages.

Sources of variation	SS	df	MSS	F	Sig.
A. Mbui Njeru					
Mosquito counts/house	7009.1	3	2336.4	0.985	**
B. Mathangauta					
Mosquito counts/house	35661.5	3	11887.2	1.116	**

SS = Sum of squares
df = Degrees of freedom
MSS = Mean sum of squares
F = Variance ratio
Sig.= Significance
** = Highly Significant (P<0.01)

Figure 3.10. **Monthly rainfall and counts of vector mosquitoes collected in Mbui Njeru by CDC light trap.**


Monthly rainfall (mm)
500
400
300
200
100
0
F M A M J J A S O N D J F
1990
1991
Months
Monthly rainfall

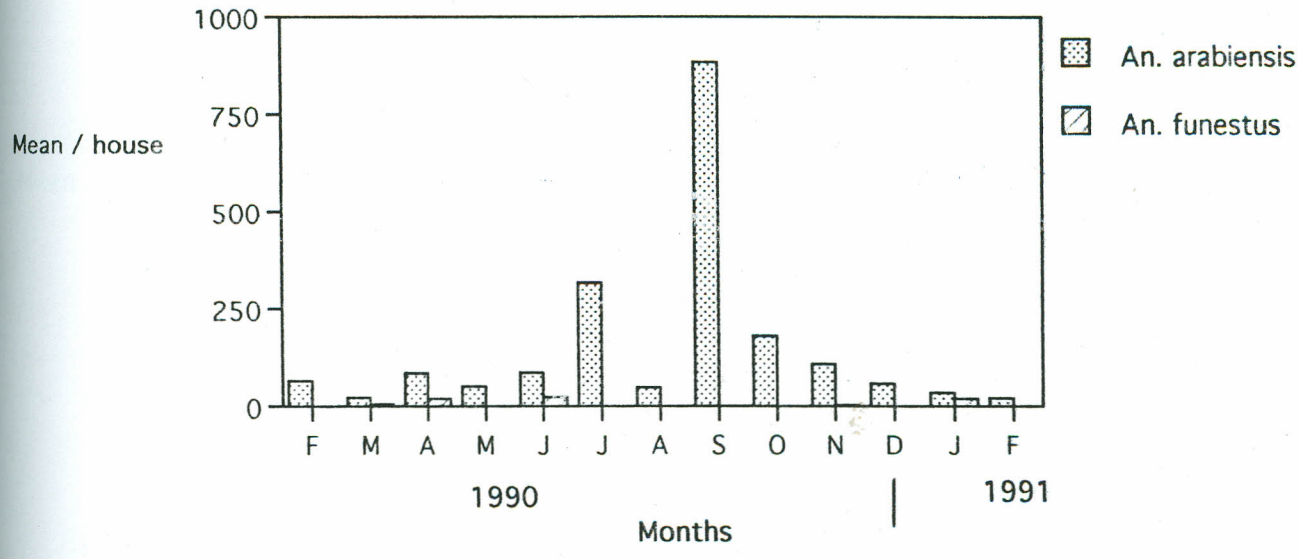
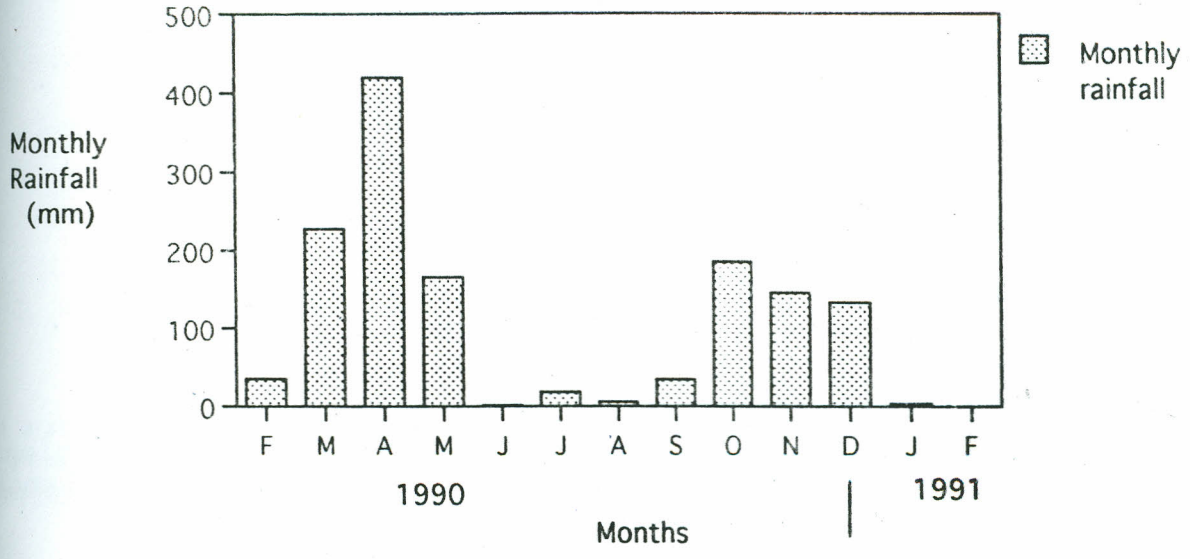

Mean / house
1000
750
500
250
0
F M A M J J A S O N D J F
1990
1991
Months
An. arabiensis
An. funestus

Figure 3.11. **Monthly rainfall and counts of vector mosquitoes collected in Mathangauta village by CDC light trap**


Monthly Rainfall (mm)
500
400
300
200
100
0
F M A M J J A S O N D J F
1990
1991
Months
Monthly rainfall

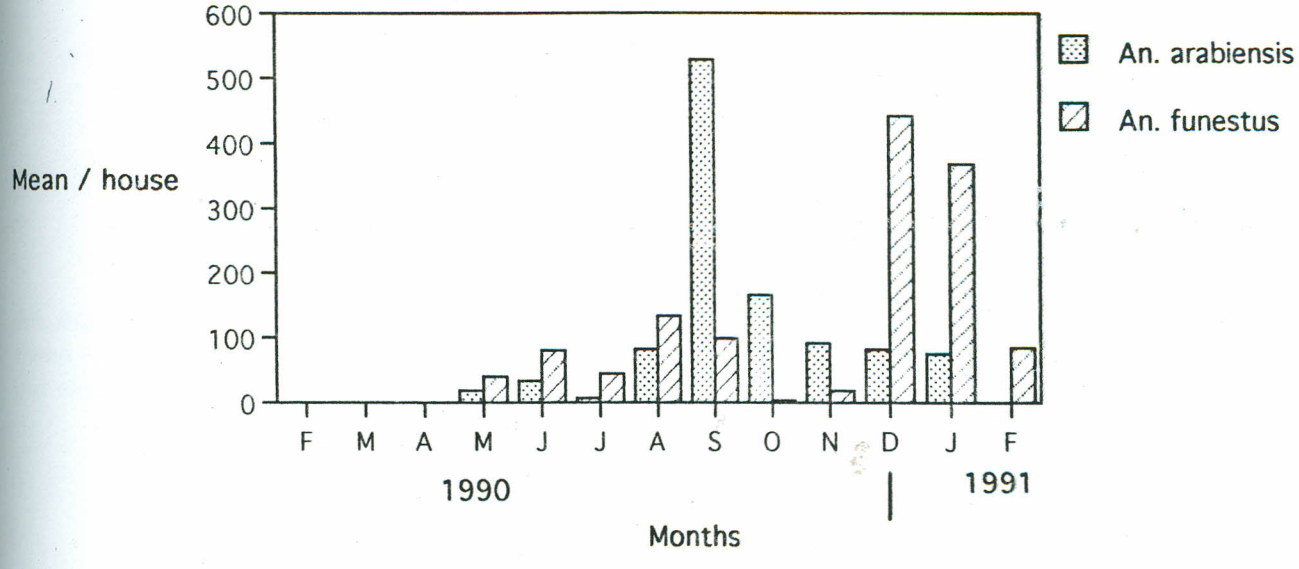
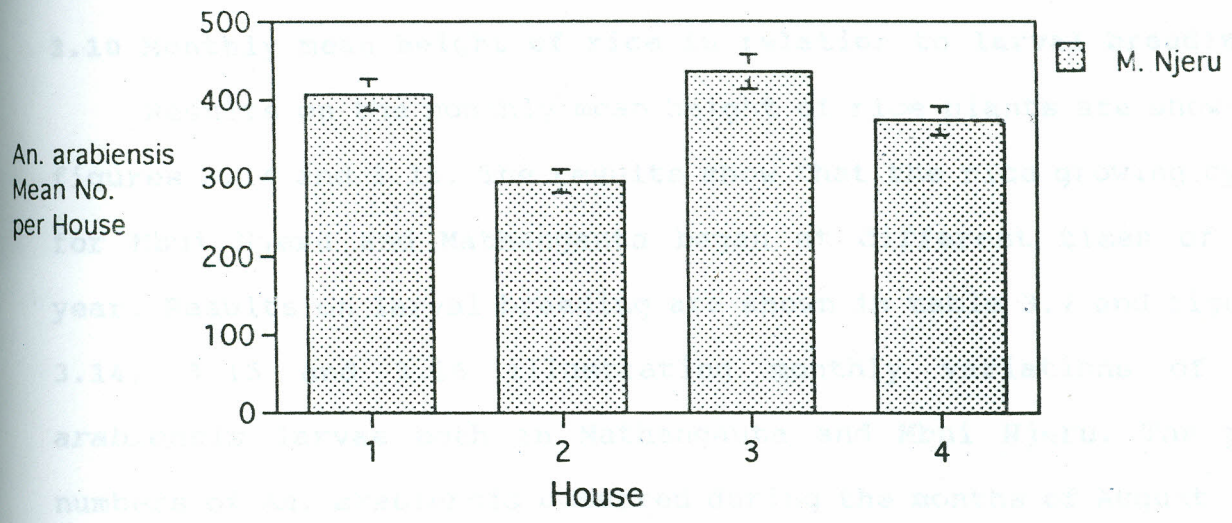
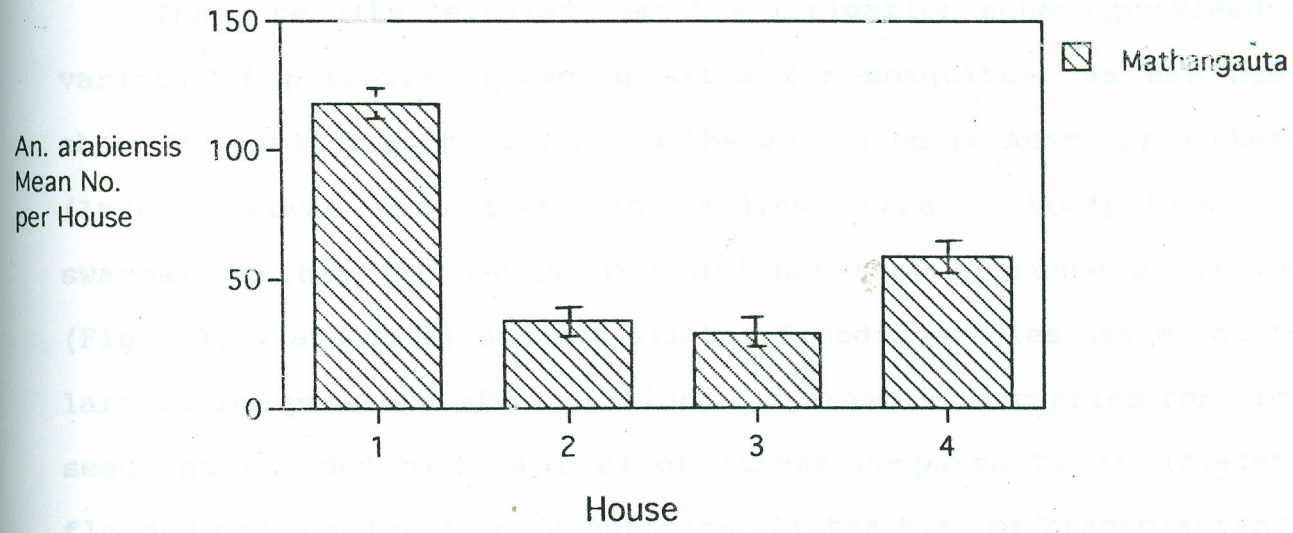

Mean / house
600
500
400
300
200
100
0
F M A M J J A S O N D J F
1990
1991
Months
An. arabiensis
An. funestus

Figure 3.12. **Mean numbers and standard errors of *An. arabiensis* from different houses in Mbui Njeru and Mathangau villages.**

a) Mbui Njeru



b) Mathangauta



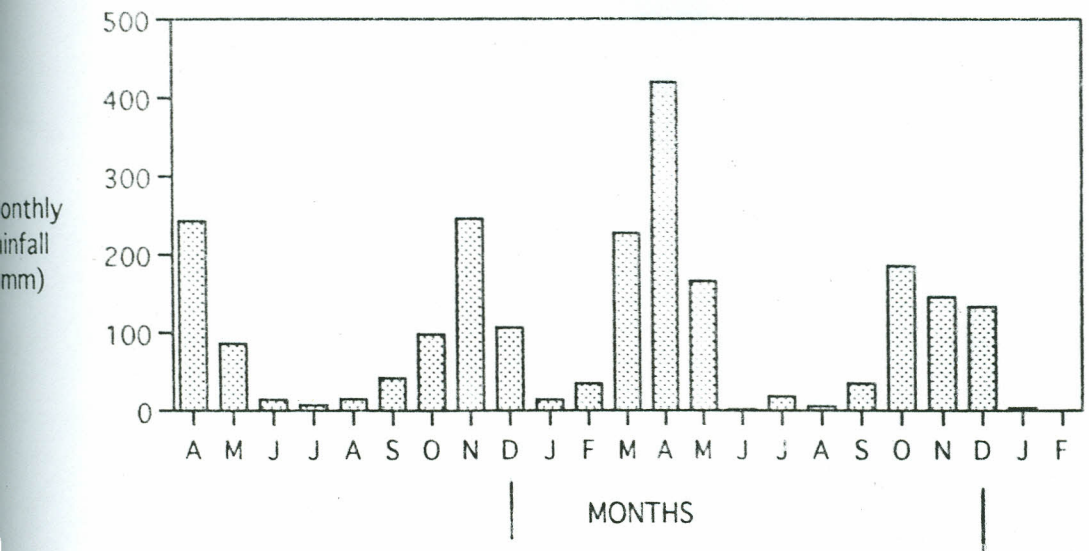
houses while in Mathangauta village this was observed in house number 1 (Table 3.7). In Mbui Njeru house number 1 was 58m from the nearest paddy while house number 4 was 88m away (Fig. 2.3). In Mathangauta house number 4 was 63m from the nearest paddy, but house number 1 which was 66m away had the highest number of mosquitoes (829) and was 3m further away from the paddies than house number 4.

3.10 Monthly mean height of rice in relation to larval breeding.

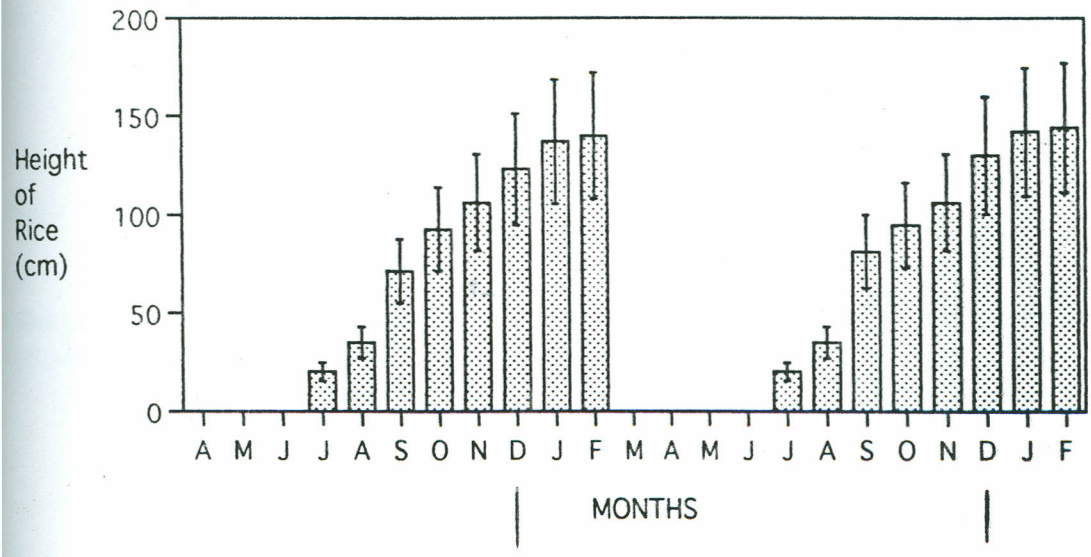
Results on the monthly mean height of rice plants are shown in figures 3.14 and 3.15. The results show that the rice growing cycle for Mbui Njeru and Mathangauta began at different times of the year. Results on larval breeding are shown in table 3.7 and figures 3.14, 3.15 and 3.16 illustrating monthly variations of *An. arabiensis* larvae both in Mathangauta and Mbui Njeru. The peak numbers of *An. arabiensis* occurred during the months of August 1989 and July 1990 in Mbui Njeru village while in Mathangauta it occurred in October 1989 and July 1990 (Fig. 3.16).

These results revealed that the irrigation scheme provided a variety of potential breeding sites for mosquitoes as has been shown by earlier workers such as the work done in Ahero by Surtees (1970). Larvae were found in paddies, canals, hoofprints and swamps. Freshly flooded paddies did not show presence of larvae (Figs. 3.14 and 3.15) and not all the flooded paddies had mosquito larvae. The presence of vegetation, for example, nurseries for rice seedling yielded high numbers of larvae compared to an adjacent flooded paddy without any vegetation. At the time of transplanting,

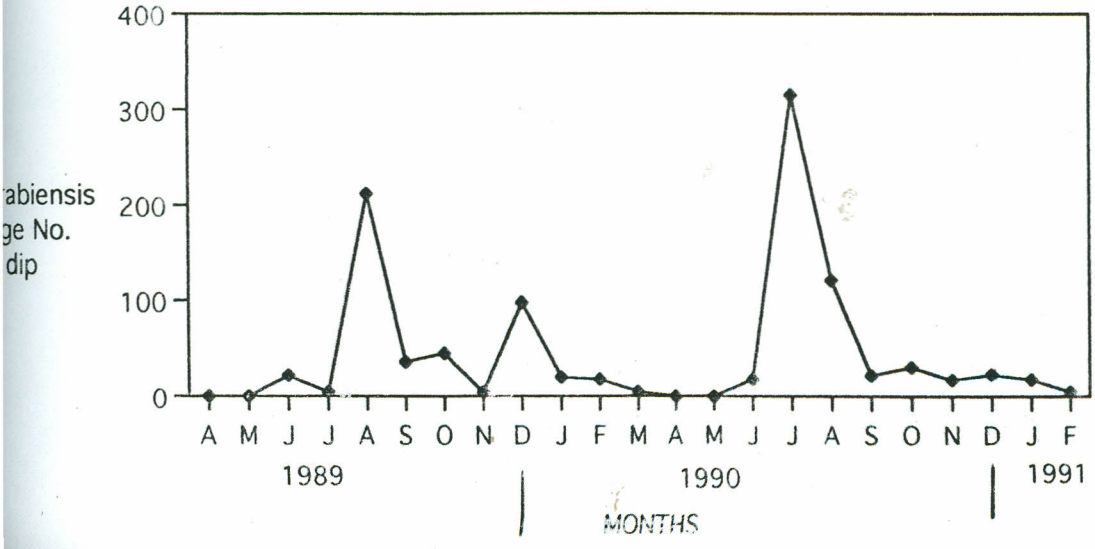
Figure 3.14. **Monthly numbers of *An. arabiensis* larvae coll in Mbui Njeru in relation to the average heig rice and rainfall.**



onthly
ainfall
mm)

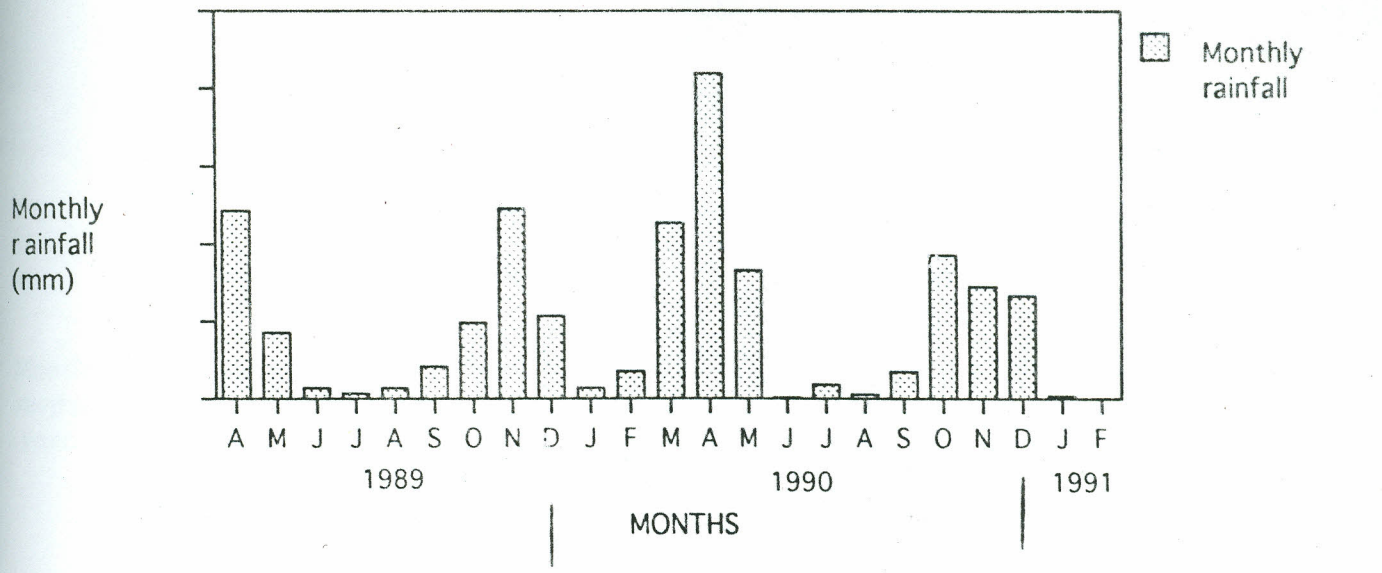


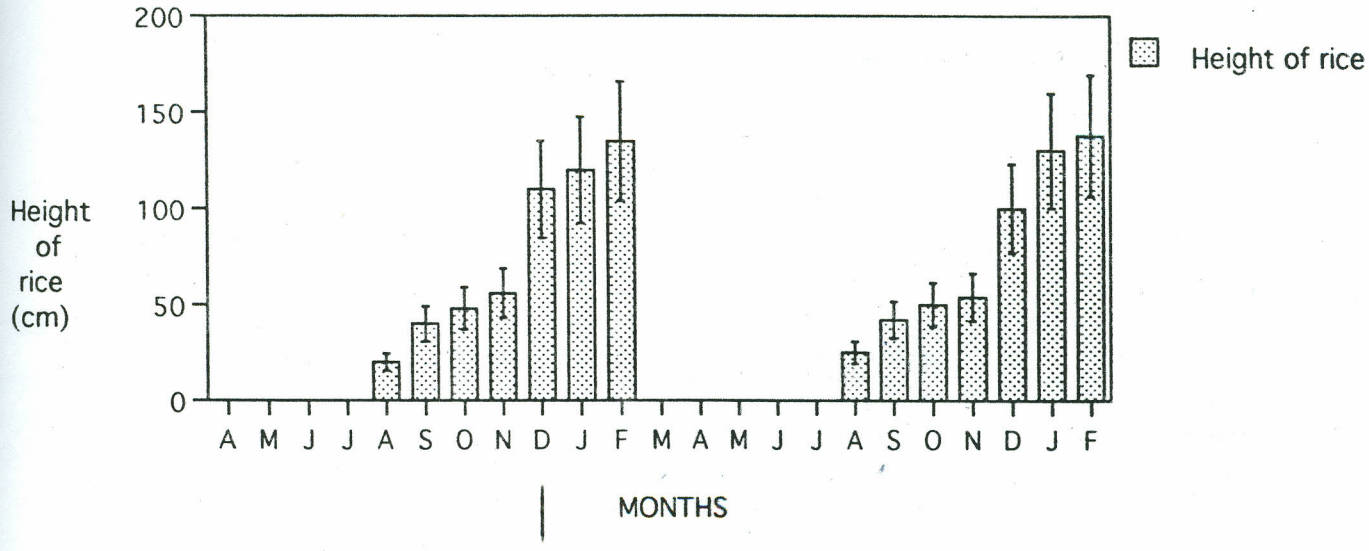
Height
of
Rice
(cm)



abiensis
ge No.
dip

Figure 3.15. **Seasonal numbers of *An. arabiensis* larvae collected in Mathangauta in relation to the average height of rice and rainfall.**


Monthly rainfall (mm)
Monthly rainfall
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
MONTHS


Height of rice (cm)
200
150
100
50
0
Height of rice
A M J J A S O N D J F M A M J J A S O N D J F
MONTHS

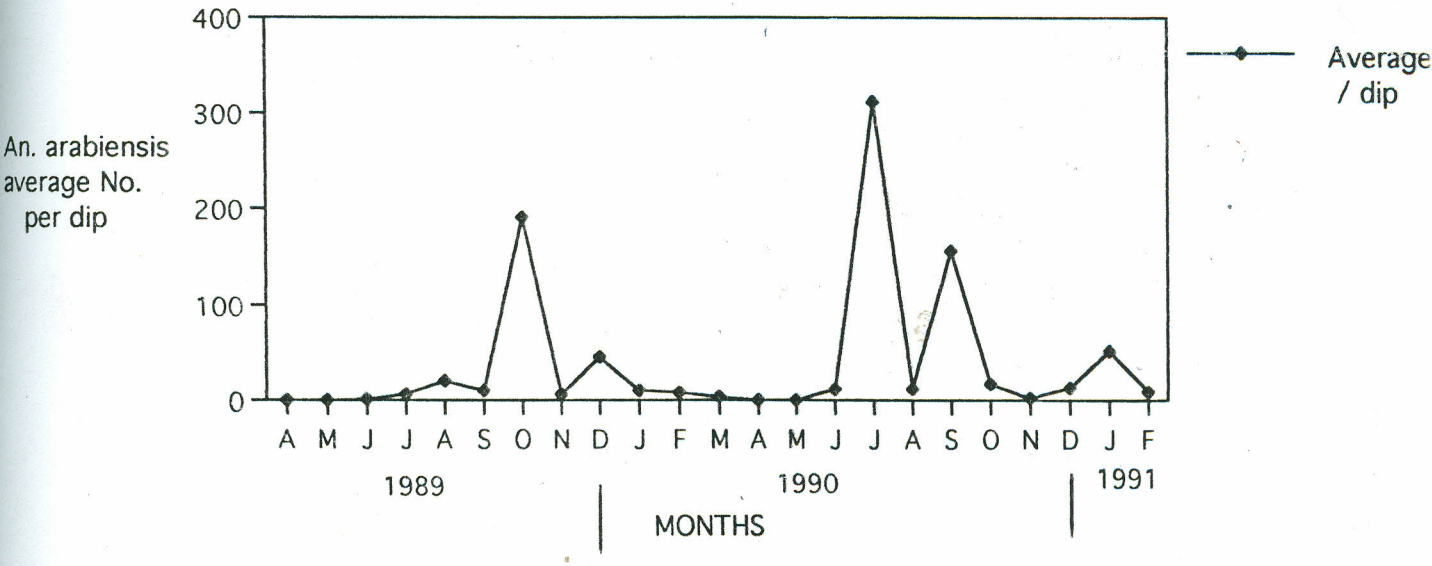
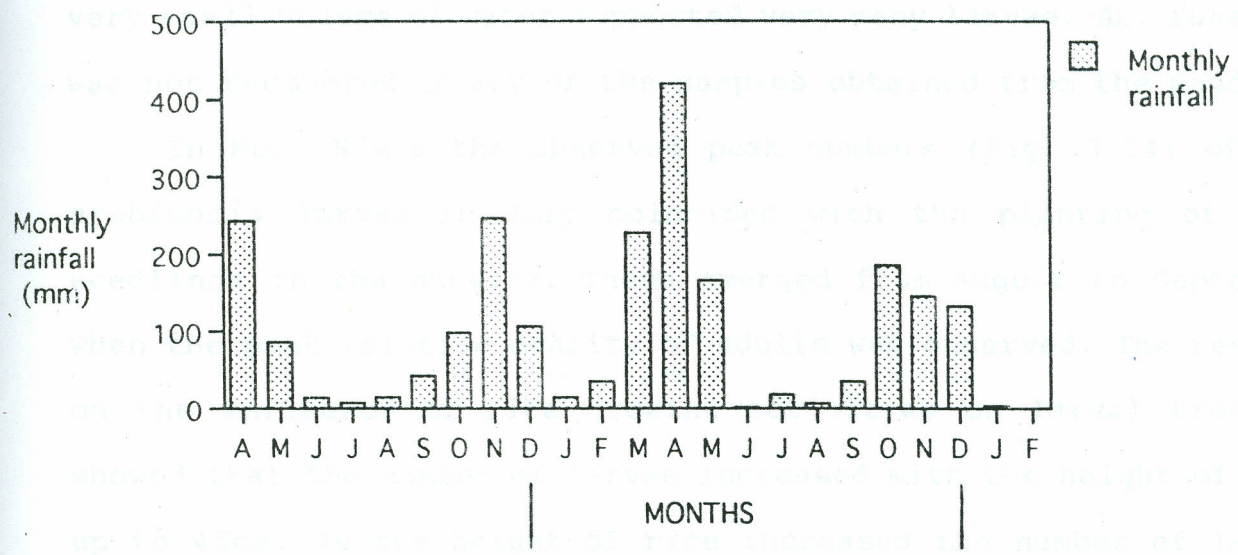
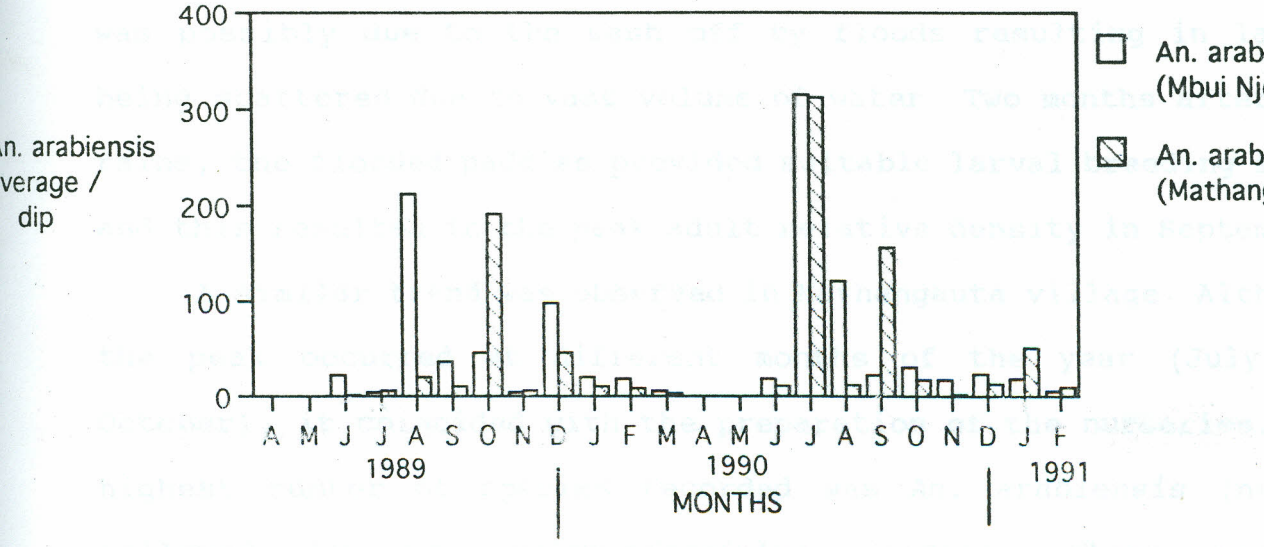

An. arabiensis average No. per dip
400
300
200
100
0
Average / dip
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
MONTHS

Figure 3.16. **Monthly distribution of *An. arabiensis* larvae in Mbui Njeru and Mathangauta villages.**


500
400
300
200
100
0
Monthly rainfall (mm)
A M J J A S O N D J F M A M J J A S O N D J F
MONTHS
Monthly rainfall


400
300
200
100
0
An. arabiensis average / dip
A M J J A S O N D J F M A M J J A S O N D J F
1989
1990
1991
MONTHS
An. arabiensis (Mbui Njeru)
An. arabiensis (Mathangauta

the rice seedlings and the footprints provided suitable breeding sites for the larvae of *An. arabiensis*. Hoofprints though having very small volume of water supported very many larvae. *An. funestus* was not recovered in any of the samples obtained from the paddies.

In Mbui Njeru the observed peak numbers (Fig. 3.14) of *An. arabiensis* larvae in July coincided with the planting of rice seedlings in the nursery. These emerged from August to September when the peak relative density of adults was observed. The results on the influence of rice growing activities on larval breeding showed that the number of larvae increased with the height of rice up to 45cm. As the height of rice increased the number of larvae decreased. During the peak rainy season of April and May 1989 and 1990 the numbers of larvae decreased (Figs. 3.14 and 3.15). This was possibly due to the wash off by floods resulting in larvae being scattered due to vast volume of water. Two months after the rains, the flooded paddies provided suitable larval breeding sites and this resulted in the peak adult relative density in September.

A similar trend was observed in Mathangauta village. Although the peak occurred at different months of the year (July and October), it coincided with the preparation of the nurseries. The highest number of species recorded was *An. arabiensis* (n=883) followed by *Cx. quinquefasciatus* (n=256). These results corresponded to the reported high counts of adult *An. arabiensis* recorded. Although higher counts of larvae were recorded from paddies because there were relatively more paddies sampled, it was observed that the nurseries supported mosquito larval breeding.

3.11 Discussion

The differences observed in the numbers of mosquito vectors in the two villages could be attributed to the fact that the two villages occupy different positions in the irrigation scheme in relation to location of rice paddies. Mbui Njeru lies in the centre of the paddies and is surrounded by water from all sides while Mathangauta lies at the periphery and is only surrounded by water on one side. Consequently, there are more breeding sources for mosquitoes in Mbui Njeru village than there are in Mathangauta village. In addition, rice paddies in Mbui Njeru village are flooded much earlier from the month of March every year until December and therefore provide suitable mosquito breeding sites for a longer duration of approximately ten months. In Mathangauta, the paddies are flooded much later, from July to December. This latter duration is shorter than the former by six months. Therefore, the numbers of mosquitoes were higher in Mbui Njeru village where the paddies were flooded for a longer duration.

The specific site of mosquito collection in relation to the distance from larval habitat may directly influence the number caught. This situation was observed in Mbui Njeru where *An. arabiensis* were collected in consistently higher numbers in houses nearest the edge of rice paddies. Similar observations were made in Mathangauta. The inconsitency in some of the figures recorded from houses merely indicates that some factors other than distance of houses from paddies may also influence the numbers recorded in a particular house. It is therefore important when planning irrigation schemes to position the villages far from the paddies.

It is not clear which factors influence selection of sites for villages in the scheme, but it seems that the convenience for the work on the paddies is given priority at the expense of health impact. Collections recovered daily showed that there were daily variations in the numbers of *An. arabiensis*, implying that the samples obtained on daily basis do not necessarily represent the population density as they could be influenced by other factors such as weather and physiological status of the mosquitoes at the time of collection.

In Mbui Njeru village the peak numbers of *An. arabiensis* which occurred in September/October coincided with the presence of rice seedlings in the paddy nurseries, implying that the presence of vegetation in the paddies encouraged the breeding of mosquito larvae and therefore resulted in an increase in mosquito output. Similar results have been reported by Chandler and Highton (1975) while working in Ahero Irrigation scheme. The higher peak of *An. arabiensis* during the second year of study was probably due to the fact that the mosquito output conforms to the rice growing cycle activities such as flooded paddies or nursery preparation which take place at the same time each year.

Evidence of rice fields being inhabited by mosquitoes throughout all stages of plant growth is well documented (Chang *et al.*, 1950; Chow, 1969; Palchick and Washino, 1985). Often the utilization depends on the height and density of rice plants. There were asynchronous peaks of *An. arabiensis* and *An. funestus* occurring at different times of the year and rice growing activities. The respective mosquitoes breed in different ecological

niches whose occurrences are influenced by seasons and the type of rice activities. It was observed that flooded rice paddies with vegetation favoured *An. arabiensis*. Paddies with shorter rice favoured mosquito breeding than with taller rice. Other workers have also shown that planted short nursery rice supports prolific breeding by *An. gambiae* s.l. (Webbe, 1961; Surtees *et al.*, 1970), while the drainage canals provided the breeding sites for *An. funestus*.

Water drained from the paddies during harvesting in December and January accumulates in the canals. This is the period when the rice is mature and ready for harvesting. In Mathangauta village, the peak numbers of adult *An. funestus* observed in January coincided with the dry season, when the paddies are dry and rice is being harvested. Several previous workers had reported the invasion of older stands of rice by *An. funestus* (Grainger, 1947; Chandler and Highton, 1975), but according to other reports *An. funestus* is not normally found in the rice paddies (Service, 1977; Carnevale and Robert, 1987; Robert *et al.*, 1988). Other past studies did not differentiate that *An. funestus* were breeding in the canals rather than in the paddies during this stage of the rice growing activity. Other species of mosquitoes that are associated with more established stands of rice are *An. pharoensis*, *Cx. poicilipes* and *Cx. univittatus*. The reason for higher numbers of *An. funestus* recorded in Mathangauta village compared to Mbui Njeru village was probably due to more extensive farming activities in Mathangauta. Apart from the canals near the paddies, individual farmers have created numerous water channels through which water is directed

into the gardens. These form suitable breeding sites for *An. funestus*.

Three methods for collection were used for sampling mosquitoes i.e the hand catch, pyrethrum spray catch and CDC light trap methods. The inference is that if only one method of collection is used, the samples will not be an accurate estimate of the relative density of mosquitoes. A combination of the methods gives a better representation of the mosquito species composition. The results of collection using different methods showed that the pyrethrum spray catch method was more reliable than the other methods when sampling indoor resting mosquitoes. Workers who have compared various mosquito sampling methods have shown that trap performance and sampling procedures vary considerably depending on the position and type of house (Gillies, 1955; Service, 1964), time of trapping (Viswanathan *et al.*, 1950), site and species (Downe, 1960; Breeland, 1972a, b). The efficiency of the hand-catch method has been assessed in a number of studies in different places (Ribbands, 1946a; Viswanathan *et al.*, 1952; Muirhead-Thompson and Mercier, 1952; Bailly-Choumara, 1973). Their results showed that after completion of these hand catch collections, if the spray catch collection was carried out immediately, more mosquitoes that had been left out can still be recovered, showing that during the hand catch method only some mosquitoes are collected while others are missed out. However, it should be realised that each of the three collection methods has its own advantages and disadvantages. For example, with the spray catch method the numbers of mosquitoes caught are high but the insecticides kill off most of the

mosquitoes collected and this limits the determination of sporozoite rates thereafter through dissection. In terms of quantitative determination of mosquitoes resting indoors the pyrethrum spray catch method offers a reliable samplimg method. The CDC light trap collection method has limitation when sampling mosquitoes in that it excludes all the mosquitoes that are not active since it samples only mosquitoes that are flying.

The onset of heavy rains always gives low counts of larvae because of wash out effects in small pools and streams, while in larger collections the small numbers of mosquitoes originally present become scattered over wide areas of water and are therefore difficult to find. In other words although sampling of larvae in a malaria survey is inevitable, there is lack of a standard reliable technique for quantitative estimates of larval population size which can make the results closest to having a good method for collection. However, it is essential to determine the potential for mosquito breeding as a guide to the type of adults in an area.

In Mbui Njeru the observed peak numbers of *An. arabiensis* larvae in July coincided with the planting of rice seedlings in the nurseries. *An. arabiensis* larvae emerged from August to September when the peak adult relative density was observed. During the rainy season the numbers of larvae decreased. This was probably due to the wash off of larvae by floods. The flooded paddies provided stable larval breeding site three months after the rains, and this resulted in the peak adult relative density in September. A similar trend was observed in Mathangauta village. Although the peaks occurred during different months of the year, it coincided with the

preparation of the nurseries. The failure to collect *An. funestus* from the paddies was also reported by Service (1977) and Robert *et al.*, (1988) whose findings refuted earlier reports by several authors, that *An. funestus* had been observed to invade older stands of rice (Grainger, 1947; Webbe, 1961; Chandler and Highton, 1975)

These findings are important in relation to malaria transmission. Two known vectors of malaria in Kenya *An. arabiensis* and *An. funestus* were recorded. The presence of the above vectors shows the potential for malaria prevalence in this area. However, the presence of *An. arabiensis* and *An. funestus* alone does not give an indication on the interraction between the vector, human host and malaria transmission. It is therefore necessary to carry out further investigations to determine the role of the vectors in malaria transmission in the area studied.

CHAPTER 4

4 Feeding and resting behaviour of mosquitoes

4.1 Introduction

4.1.1 Movement and resting behaviour

Some female mosquito species usually enter a house from dusk to take blood meals, after which they seek resting places in which to shelter in order to allow the digestion of their food. A number of mosquito resting sites have been described by several workers (Gillies, 1954, Service, 1971a). Different types of shelters have been utilized as resting sites by mosquitoes. Examples include indoor resting sites such as houses, barns and outdoor resting sites such as animal burrows, pits, hollow trees, cracks, crevices in the ground and vegetation cover. These habitats provide a wide range of microclimatic conditions leading to species specific preferences for resting in particular habitats. The female mosquitoes such as *Anopheles* frequently prefer the lower portions of the interiors of houses where temperatures are low and humidity is high.

Special terms have been used in relation to the resting behaviour. Endophily is the habit of remaining within a man-made shelter throughout the whole or a definite part of the gonotrophic cycle. Exophily is the habit of spending the greater part of the gonotrophic cycle out of doors (Bruce-Chwatt, 1985).

The preference for resting site can vary depending on environmental factors such as excessive sunlight and wind. Even with a species such as *An. gambiae s.s.* which is regarded as highly endophilic, a certain proportion of the population may continue to

rest out doors (Gillies, 1954), although suitable resting indoor sites may be available.

Prior knowledge of resting behaviour of adult mosquitoes is an important consideration when planning mosquito control. The epidemiological importance of exophily exhibited by malaria mosquito vectors have been studied (Gillies, 1956). In malaria control campaigns involving mosquito vectors carried out in the past, interior surfaces of houses, such as wall and ceillings, have usually been sprayed with residual insecticides such as DDT to kill adult mosquitoes coming and resting on those surfaces. This approach is mainly effective in controlling malaria if the mosquito vectors are endophilic.

4.2 The feeding behaviour of mosquito species

4.2.1 Sources of blood meal

Adult female mosquitoes require a blood meal to enable the maturation of ovaries in order to lay viable eggs. During the course of taking a blood meal, disease organisms in the infective vectors are transmitted to the host. The proportion of blood meals that a vector population takes on man is relevant for the transmission of malaria. Transmission is enhanced if a large number of the vector populations were to take all their blood meals on man. Unfortunately, it is difficult to assess the average source of blood meals of vector population and degree of uniformity in this aspect. The studies of host-vector relationships of arthropod vectors of disease to man and domestic animals have been determined by identification of the vector's blood meals (Garett-Jones, 1964;

Garret-Jones *et al.*, 1980). Various methods have been used to determine a mosquito population's source of blood meals. These involve - direct field observation and attraction to baits of different host species and use of serological methods (Tempelis, 1975). The latter method is the more widely used.

4.2.2 The host preference indices

Several indices have been proposed for determining the choice of host. For malaria, the most frequently used indices are the Human blood index (HBI), Forage ratio and Feeding index.

Mosquitoes demonstrate either restricted or opportunistic patterns of feeding. The feeding pattern of mosquitoes is determined by several factors which may be intrinsic or extrinsic. Little is known of the underlying genetic mechanisms of feeding but various environmental factors that influence feeding preference are mosquito-host proximity, flight pattern and inaccessibility of the hosts (Edman, 1971). Temperature, photoperiod, wind and animal densities are also known to influence feeding behaviour (Tempelis, 1975). The relationship of mosquito density to host selection has been well documented (Edman and Lea, 1972). Feeding patterns of mosquitoes may also be influenced by the availability of animal host which may divert certain mosquitoes from humans depending on the immediate available host in the case of exophagic mosquitoes.

The aims of the present studies were to obtain information on the resting habits of *An. arabiensis*, *An. funestus* and other mosquitoes. By examining the appearance of the abdomen, it is possible to determine whether mosquitoes are endophilic or

exophilic. In addition, blood meals of *An. arabiensis* and other mosquitoes collected from both indoor and outdoor resting sites were also analysed to determine host preference.

4.3 Materials and methods

4.3.1 Determination of densities in resting sites.

Adult female *An. arabiensis* and *An. funestus* mosquitoes collected from Mbui Njeru and Mathangauta villages were separated depending on the physiological state of abdomen under a dissecting microscope. *An. rufipes* which was collected from Mathangauta was also tested for the state of abdomen. The collections were carried out from the month of April 1989 to February 1991. The data from hand collection and the pyrethrum spray catch collections were recorded.

4.3.2. Blood meal analysis

Smears of stomach contents of the fed adult female *An. arabiensis*, *An. funestus* and other mosquito species were made on labelled Whatman filter papers. The mosquitoes processed for blood meal analysis were collected using the hand collection and spray catch methods. These were then air dried and placed individually in polythene bags and sent to the "Institut fur Veterinarmedizin" in Germany for the identification of the source of blood meal.

4.4 Statistical data analysis

The data on the physiological state of abdomen collected were

compiled and the mean for indoor and outdoor resting female *An. arabiensis* and *An. funestus* compared. These were tested using the X^2 test to determine if the differences observed were significant.

The proportion of the different species of mosquitoes that had fed on different hosts were determined by calculating the percentages. Chi-square test was carried out to compare the difference between the proportions of *An. arabiensis* and *An. funestus* collected indoors and outdoors feeding on human, bovine and any other hosts. Feeding Index was calculated to determine the host preference.

4.5 Results

4.5.1. Movement and resting behaviour

Results on the studies of the movement and resting behaviour of female *An. arabiensis* and *An. funestus* collected in Mbui Njeru and Mathangauta villages are summarised in figures 4.1, 4.2, 4.3, 4.4 and Appendix 4. The results of the proportions of the vector *An. arabiensis* mosquitoes presenting different physiological state of abdomen in the indoor and outdoor resting sites for both Mbui Njeru and Mathangauta are shown in table 4. The significance of the differences between the numbers of *An. arabiensis* and *An. funestus* showing different physiological state of abdomen in the indoor and outdoor resting sites for both Mbui Njeru and Mathangauta was tested. There were no significant differences in numbers with respect to the stomach condition within the habitat where the mosquitoes were caught ($F_{3,4}=0.6$; $P>0.05$), but there were

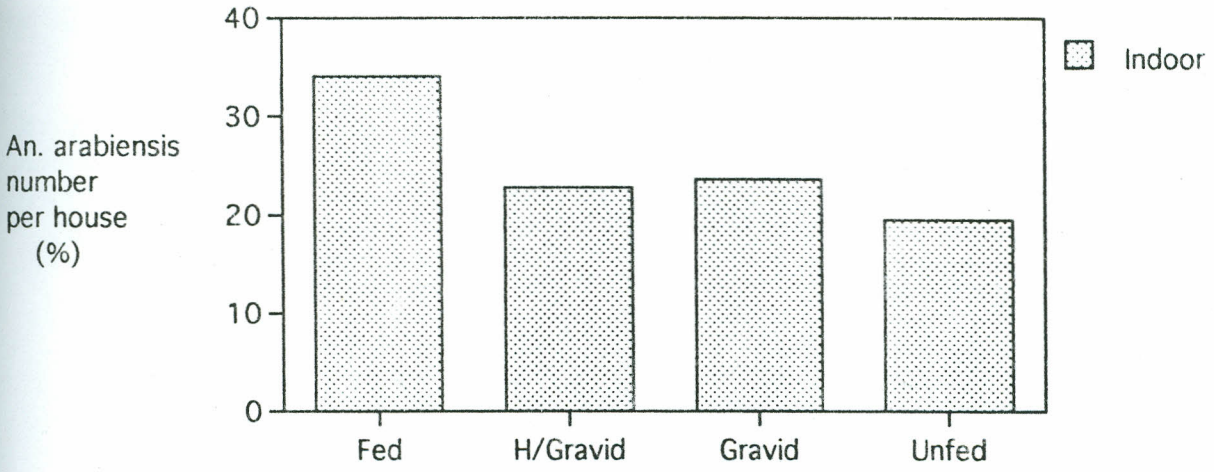
Table 4. Analysis of the numbers of *An. arabiensis* in Mbui Njeru and Mathangauta in different physiological stages caught resting indoors and outdoors.

		F	H/G	G	UF	Total	X^2	P	Sig.
A. Mbui Njeru									
Indoors	n	3742	2504	2595	2143	10984	144	7.8	**
	%	31.6	21.1	21.9	18.1				
Outdoors	n	202	134	202	317	855			
	%	1.7	1.1	1.7	2.7				
Total		3944	2638	2797	2460	11839			
B. Mathangauta									
Indoors	n	1194	920	812	554	3480	23.9	7.8	**
	%	32.9	25.4	22.4	15.3				
Outdoors	n	31	28	49	38	146			
	%	0.8	0.8	1.4	1.04				
Total		1225	948	861	592	3626			

F = Fed
H/G = Half Gravid
G = Gravid
UF = Unfed
X^2 = Chi-square value
P = Probability
Sig. = Significance
** = Highly significant

Figure 4.1. **Distribution of *An. arabiensis* in Mbui Njeru found in different abdominal physiological stages caught resting indoors and outdoors.**

a) Indoor



b) Outdoor

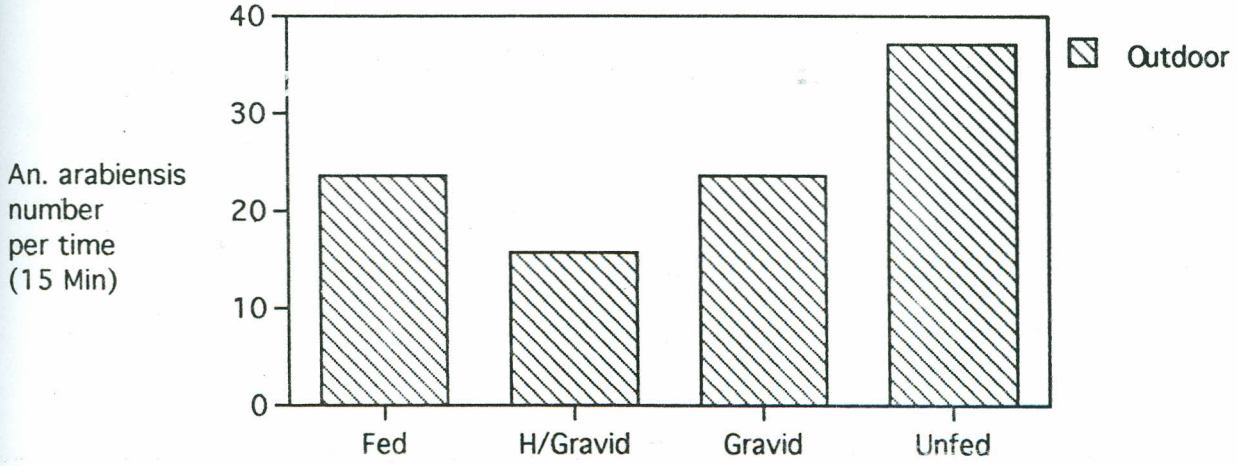
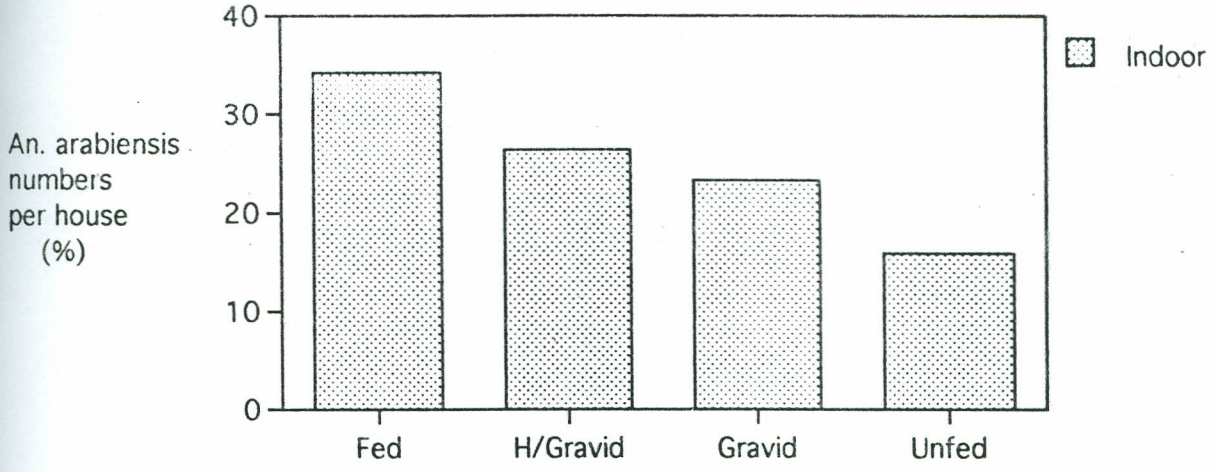


Figure 4.2. **Distribution of *An. arabiensis* in Mathangauta found in different abdominal physiological stages caught resting indoors and outdoors.**

a) Indoor



b) Outdoor

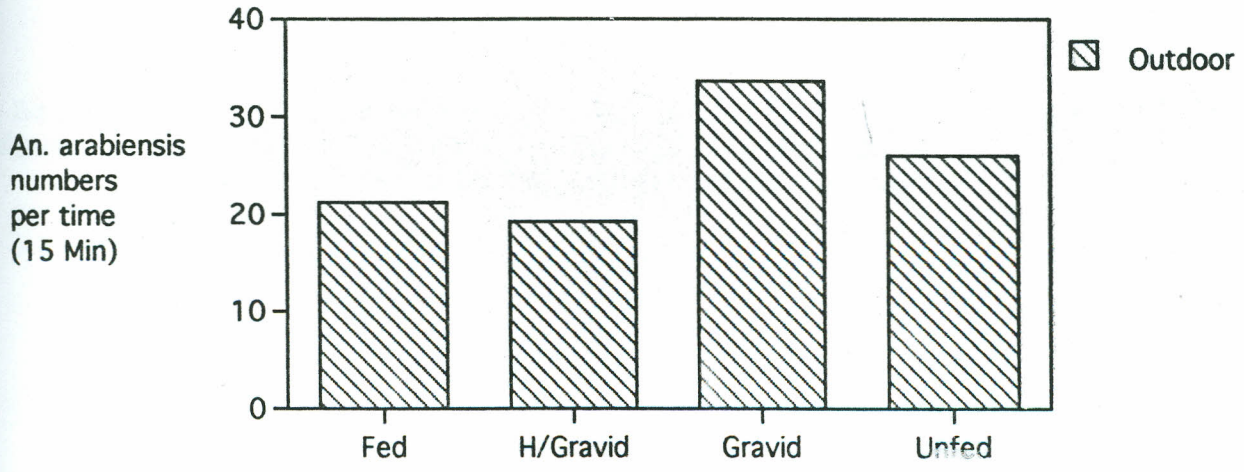
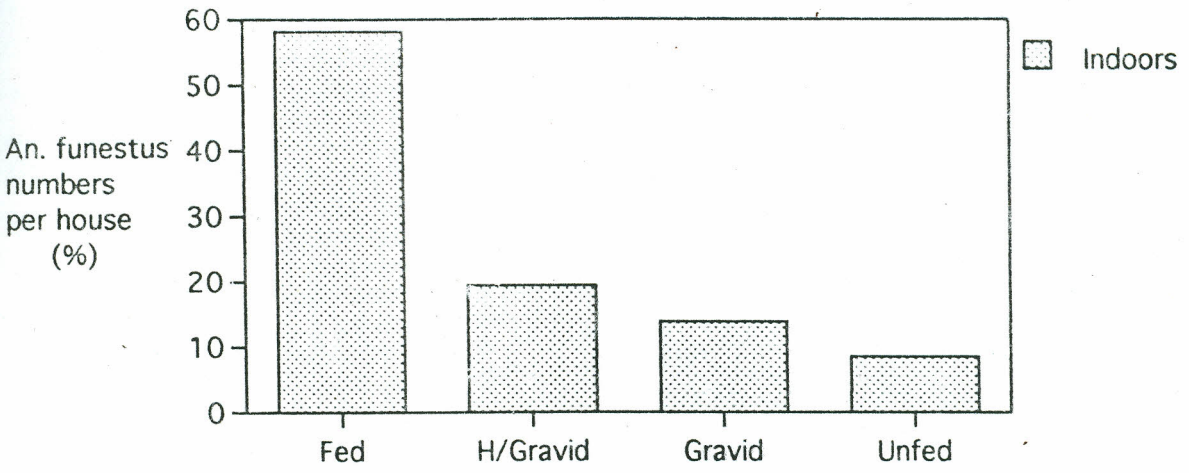


Figure 4.3. **Distribution of *An. funestus* in Mbui Njeru found in different abdominal physiological stages caught resting indoors and outdoors.**

a) Indoor



b) Outdoor

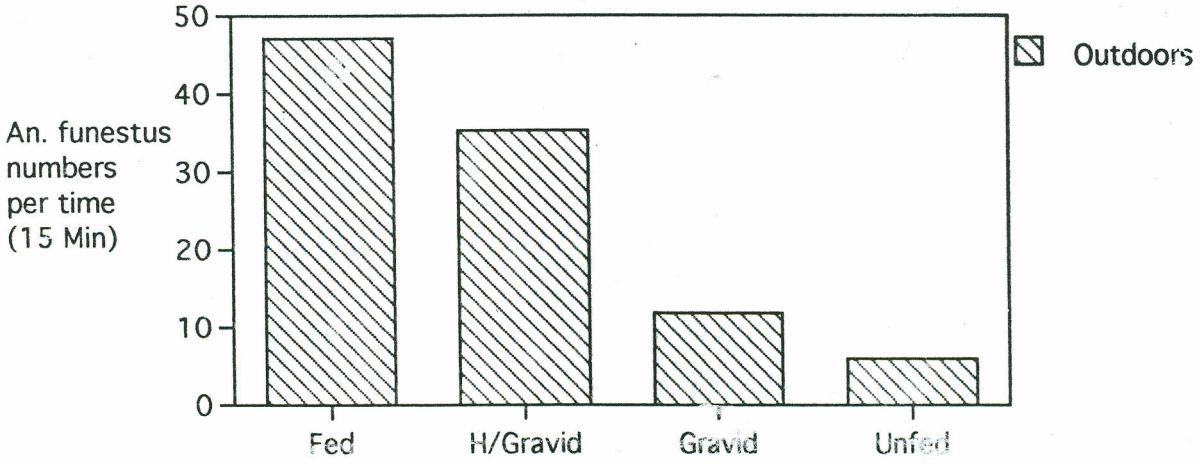
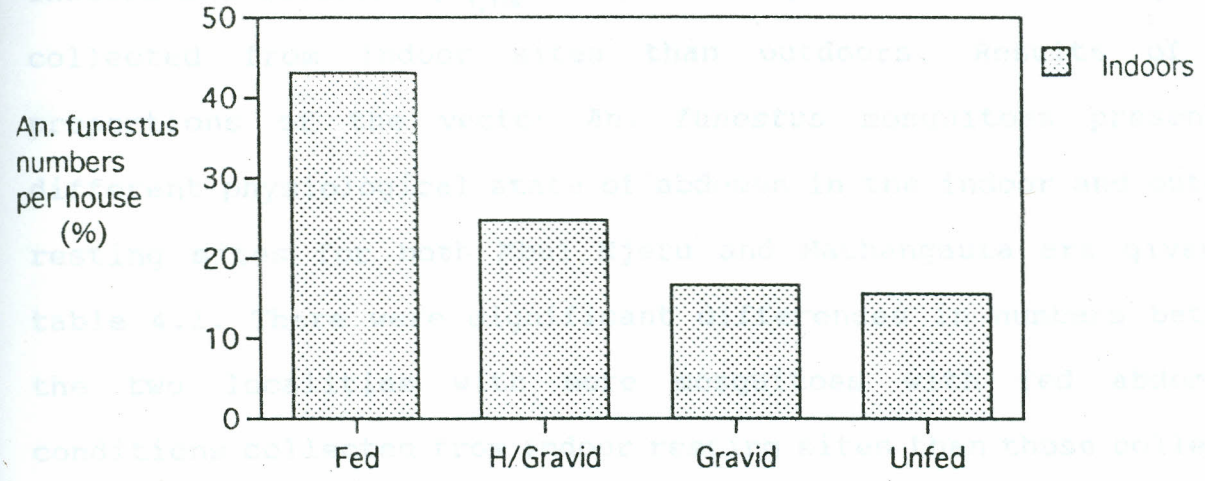
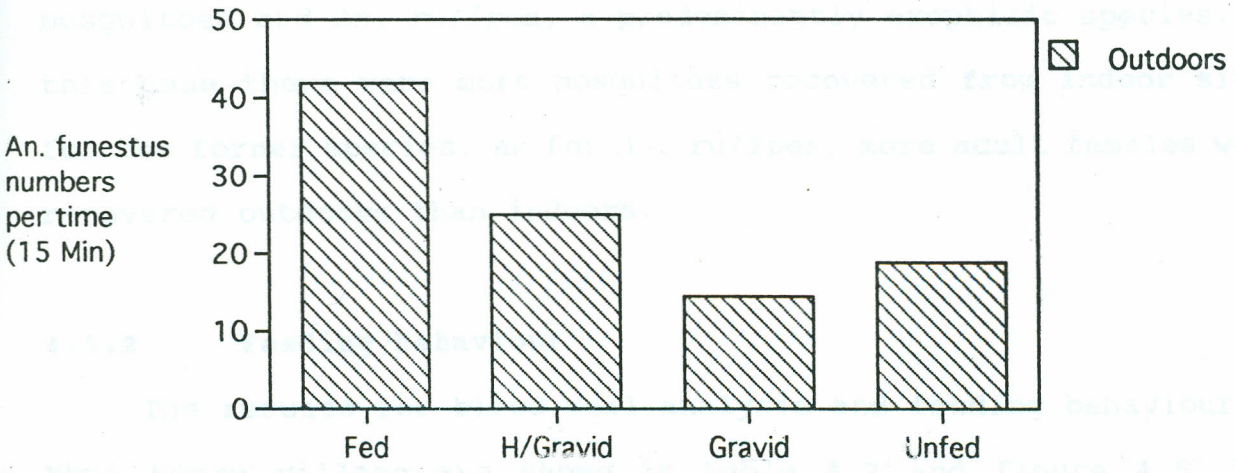


Figure 4.4. **Distribution of *An. funestus* in Mathangauta found in different abdominal physiological stages resting indoors and outdoors.**

a) Indoor



b) Outdoor



significant differences in numbers between the two localities i.e indoors and outdoors ($F_{1,176}$=27.6; P<0.001) with more fed mosquitoes collected from indoor sites than outdoors. Results of the proportions of the vector *An. funestus* mosquitoes presenting different physiological state of abdomen in the indoor and outdoor resting sites for both Mbui Njeru and Mathangauta are given in table 4.1. There were significant differences in numbers between the two localities with more mosquitoes with fed abdominal conditions collected from indoor resting sites than those collected outdoors.

Figure 4.5 shows the differences observed between *An. arabiensis* and *An. funestus* both considered to be endophilic mosquitoes and *An. rufipes*, a predominantly exophilic species. In this case there were more mosquitoes recovered from indoor sites for the former species. As for *An. rufipes*, more adult females were recovered outdoors than indoors.

4.5.2 Feeding behaviour

The results for blood meal analysis and feeding behaviour in Mbui Njeru village are shown in table 4.2 and figure 4.5. The results show that *An. arabiensis* has a wide range of hosts which include humans, bovine, as well as other hosts. Among *An. arabiensis* collected indoors in Mbui Njeru village, 48% had fed on bovine while 30% had fed on human and 20% had fed on several other hosts including fellide and chicken. Results of *An. arabiensis* collected outdoors showed that 3% had fed on human while 46% had fed on bovine and 33% had fed on other hosts. The overall number of

Table 4.1. **Analysis of the numbers of *An. funestus* in Mbui Njeru and Mathangauta in different physiological stages caught resting indoors and outdoors.**

		F	H/G	G	UF	Total	X^2	P	Sig.
A. Mbui Njeru									
Indoors	n	198.0	66.0	47.0	29.0	340	3.5	7.8	**
	%	55.5	18.5	13.2	8.1				
Outdoors	n	8.0	6.0	2.0	1.0	17			
	%	2.2	1.7	0.6	0.3				
Total		206	72	49	30	357			
B. Mathangauta									
Indoors	n	861.0	493.0	334.0	311.0	1999	13.5	7.8	**
	%	39.8	22.8	15.5	14.4				
Outdoors	n	67.0	40.0	23.0	30.0	160			
	%	3.1	1.9	1.1	1.4				
Total		928	533	357	341	2159			

F = Fed
H/G = Half Gravid
G = Gravid
UF = Unfed
X^2 = Chi-Square
P = Probability value
Sig.= Significance
** = Highly Significant

An. arabiensis feeding on bovine was significantly higher than those that had fed on human host (P< 0.01, d= 2.59). There was no significant difference between *An. arabiensis* and *An. funestus* with respect to those feeding on human hosts (P >0, 05, d=0.46).

The Human Blood Index (HBI) defined as "the proportion of freshly fed Anopheles found to contain human blood" was 0.02 (1155) and 0.09 (55) for *An. arabiensis* collected indoors and outdoors respectively while the Feeding Index (FI) for *An. arabiensis* collected resting both indoors and outdoors was 0.9 and 0.5 respectively (Table 4.2). Both values were less than 1 implying that there was a decrease in feeding on human and an increase in feeding on bovine in both villages.

In Mathangauta the results on the feeding behaviour of *An. arabiensis* collected indoors are shown in table 4.3 and figure 4.6. The results show that 1% fed on human hosts while 72% fed on bovines. Results of *An. arabiensis* feeding behaviour from outdoor collections showed that 3% had fed on human hosts while 76% had fed on Bovine.

4.6 Discussion

The observations that more of the vector mosquitoes collected from indoor resting sites were fully fed indicates that a high proportion of these species prefer resting indoors suggesting a more endophilic tendency. Although more *An. arabiensis* and *An. funestus* were collected from indoor resting sites, good proportions were also collected resting outdoors. The data imply that the vectors leave the huts to oviposit outdoors and some of the

Table 4.2. Host preference (Feeding Index (FI)) of *An. arabiensis* and *An. funestus* collected from indoor and outdoor resting sites in Mbui Njeru.

A. INDOORS

HOSTS	SPECIES *An. arabiensis* No.	%	*An. funestus* No.	%	FI
Human	546	30.0	2	2.6	0.9
Bovine	870	47.98	36	46.2	
Ruminant	132	7.3	14	17.9	
Others	265	14.6	26	33.3	
TOTAL	1813	99.9	78	100	

B. OUTDOORS

HOSTS	SPECIES *An. arabiensis* No.	%	*An. funestus* No.	%	FI
Human	8	11.1	0	0	0.5
Bovine	48	66.7	13	76.5	
Ruminant	6	8.3	4	23.5	
Others	10	13.9	0	0	
Total	72	99.9	17	100	

No. = Number that fed on each host
% = Percentage that fed on respective host
FI = Feeding Index
Others = Chicken, feline and those not indicating

Table 4.3. Host preference (FI) of *An. arabiensis* and *An. funestus* collected from indoor and outdoor resting sites in Mathangauta.

A. INDOORS

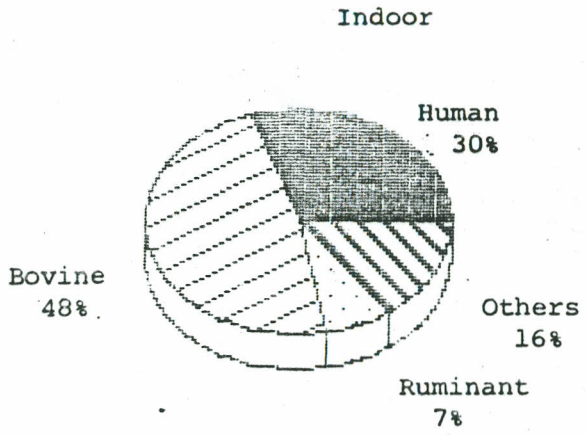
HOSTS	SPECIES *An. arabiensis* No.	%	*An. funestus* No.	%	FI
Human	7	1.4	1	0.3	0.9
Bovine	358	71.9	291	80.2	
Ruminant	41	8.2	33	9.1	
Others	92	18.5	38	10.5	
TOTAL	498	99.9	363	100	

B. OUTDOORS

HOSTS	SPECIES *An. arabiensis* No.	%	*An. funestus* No.	%	FI
Human	2	3.4	0	0	0.49
Bovine	44	74.6	25	73.5	
Ruminant	5	8.5	1	2.9	
Others	8	13.6	8	0	
Total	59	100	34	100	

No. = Number that fed on the respective host
% = Percentage that fed on the respective host
FI = Feeding Index
Others = Chicken, feline and those not indicating

Figure 4.5. **Feeding Index of *An. arabiensis* in Mbui Njeru village.**


Indoor
Human
30%
Bovine
48%
Others
16%
Ruminant
7%

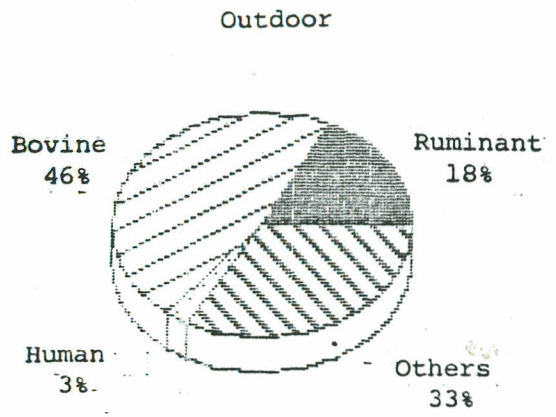
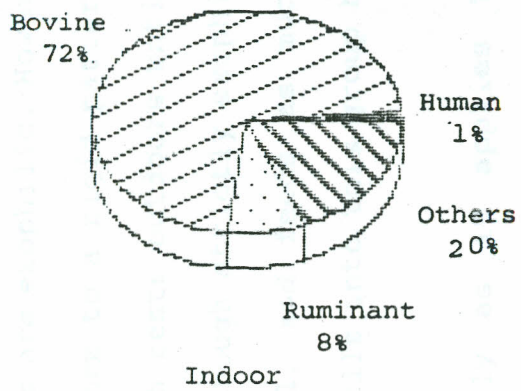
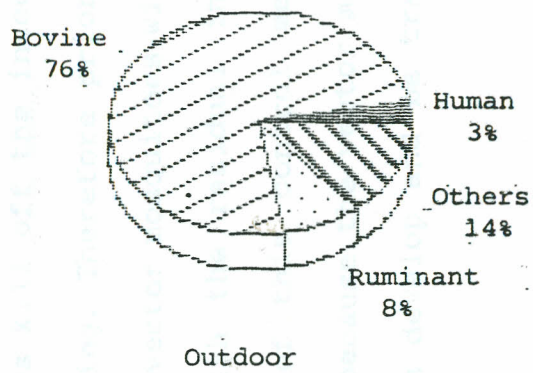

Outdoor
Bovine
46%
Ruminant
18%
Human
3%
Others
33%

Figure 4.6. **Feeding Index of *An. arabiensis* in Mathangauta village.**


Bovine
72%
Human
1%
Others
20%
Ruminant
8%
Indoor


Bovine
76%
Human
3%
Others
14%
Ruminant
8%
Outdoor

mosquitoes that have oviposited can either be found resting indoors or outdoors. In the case of *An. rufipes* the findings clearly indicate that this species is exophagic.

Reports of the resting behaviour of An. arabiensis and *An. funestus* have been well documented (Service, 1986). These reports indicate that *An. arabiensis* can rest both indoors and outdoors. *An. funestus* rests mainly indoors but can also be found outdoors. These results confirm that in Mwea, some mosquito species are truly endophilic while others are exophilic. However, there are some species which fail to conform to a rigid pattern such as *An. fluviatilis* from India which rests outdoors until oviposition and *An. aquasalis* in Trinidad, though strictly exophilic, leaves a house immediately after a meal, and feeds as much indoors as outdoors. *An. arabiensis* also falls into this group because it can rest both indoors and outdoors.

The knowledge of endophily as it applies to mosquitoes prompted widespread adoption in earlier malaria campaigns of spraying the interior surfaces of walls of houses with residual insecticides such as DDT and Fenitrothion (Joshi, 1975). The residual deposits of insecticides kill off the insects which come into contact with it while resting. Therefore prior knowledge of the indoor resting habits of the vector mosquitoes will enhance the chances of mosquito contact with the residual insecticide and therefore increase efficiency of this control method. Malaria transmission will be prevented because the vector mosquitoes will die off before the parasite can develop and be transmitted to a host.

Historically, with the development of highly effective insecticides such as DDT in the 1940s there was much optimism that malaria could be completely eradicated from Africa through mass house spraying with residual sprays. In Kenya several large scale house spraying programmes such as in the bi-annual spray rounds with DDT in Kericho district between 1946 and 1948 interrupted malaria transmission until the 1980 epidemic (WHO, 1988 Dec.; Sexton, 1990). Similarly the 1972 to 1976 spray programme using fenitrothion in Kisumu reduced infant mortality rate by 41% (Joshi *et al.*, 1975). These programmes were abandoned because of high running costs, environmental contamination by DDT and the consequent development of mosquito resistance.

The use of residual spray for the control of mosquitoes can only be effective in controlling malaria if the mosquito vectors are truly endophilic increasing their chances of coming in contact with the residual insecticide and being killed before they live long enough to transmit malaria or other diseases. The large number of anophelines killed by the residual insecticide results in a decrease in numbers of ovipositions and eventually lead to a large reduction in the population size of the vectors. Studies carried out earlier in Nigeria show that the increased degree of outdoor resting by both *An. gambiae s.s.* and *An. arabiensis* can result in the failure to interrupt malaria transmission by residual insecticide spraying as was experienced in the Garki area of Northern Nigeria (Molineaux and Gramiccia, 1980).

Studies on host-feeding patterns are essential part of understanding the epidemiology of diseases transmitted by

arthropods. Some *Anopheles* species are important vectors of malaria. In order to enhance their capabilities of disease transmission, feeding must be concentrated on human hosts. A few *Anopheles* species that are vectors of malaria are predominantly anthropophilic. But some can feed on both man and animals. The degree of anthropophily and zoophily varies according to the species. Among *An. gambiae* species complex group, it has been shown that *An. gambiae* s.s. is predominantly anthropophilic. The other members of *An. gambiae* species complex show zoophilic tendency to some extent while *An. quadriannulatus* are predominantly zoophilic.

The high preference observed for bovine blood meals in Mwea was due to the fact that the sibling species was *An. arabiensis* which is an opportunistic vector and can feed readily on both man and other animals depending on which it encounters first. There is an observation which suggests that once mosquitoes locate a potential host, they tend to persistently feed on it, even though other more suitable hosts may be present (Edman, 1974).

Feeding behaviour of *Anopheles* varies from species to species. While some feed exclusively on man, others feed on both man and other animals but the degree to which this occurs depends on the situation. The results on blood meal analysis indicate that *An. arabiensis* have high degree of zoophilic tendency. Zoophilic behaviour can be useful in the control of malaria by deflecting mosquitoes to feed on bovine instead of human host and breaking the man vector contact if cows are strategically positioned outside the houses. But it can only be applicable in areas where the sibling species vector is *An. arabiensis*. Reports on zoophilic tendencies

of mosquitoes found in riceland including several important vectors of human diseases has been highlighted in several studies carried out in Kenya (Chandler and Highton, 1976 and Joshi *et al.*, 1977). Similar results have been reported from Kisumu by Highton (1979) who was able to show that 59% of *An. arabiensis* fed on cattle and the sporozoite rate was 0.33%. *Cx. quinquefasciatus* is an endophagous species but will readily feed outdoors both on man and other animals.

Although the techniques for determining the host sources of arthropod blood meals are well established, interpretation of the results can be complex and misleading. In many reports of feeding patterns little information is given on the numbers and distribution of available hosts, and it is often assumed that blood-meal results reflect host preferences, which may not be true (Boreham and Garrett-Jones, 1973). Data from blood-meal analyses are commonly presented as percentages. Other indices that have been proposed include the Human Blood Index for anopheline mosquitoes (Garrett-Jones, 1964) and the Forage Ratio which seperates preferential from opportunistic feeding patterns of mosquitoes (Hess *et al.*, 1968). The index has been used to investigate possible seasonal shifts in feeding patterns (Hayes *et al.*, 1973). The deficiencies of the forage ratio include neglecting ecological and behavioral differences among hosts and mosquitoes and host availability and accessibility to the mosquito. It also requires a complete numerical census of the animal population which may often be difficult or even impossible. Therefore the need for a quantitative method of analysing blood meal identification resulted

in the Feeding Index method. It is defined as "the proportion of feeds on one host with respect to another divided by the expected comparative proportion of feeds on those two hosts based on factors affecting feeding". The method allows for the weighting of additional factors influencing feeding patterns (Kay *et al.*, 1979).

Therefore, the frequency with which the vector takes a blood meal and the fraction of these blood meals, that is taken on man influences its vectorial capacity. The frequency of feeding increases with temperature (Muirhead-Thomson, 1951). The fraction of blood meals that is taken on man and alternative hosts depends on availability and accessibility of hosts and on genetically determined preferences of the vector. This variation in feeding habit may have a great effect on the incidence of malaria. In certain instances in India, the percentage of human blood feeds for *An. culicifacies* varies between 2-80% (Collins *et al.*, 1983). These studies showed that human hosts were available but not accessible, therefore bovine hosts were preferred.

CHAPTER 5

5 ENDEMICITY OF MALARIA IN MWEA TEBERE IRRIGATION SCHEME.

5.1 Malaria incidence in the human population

5.1.1 Introduction

5.1.1.1 Malaria situation in Kenya

In Kenya, malaria was until the turn of the century a focal disease prevalent mainly along the Coast and Lake Victoria regions (Brennan, 1926; Anderson, 1929; Rothe, 1956; Smith, 1966). Malaria spread during the construction of the railway line, as well as the World War 1 and settlement in the highlands in the early 1920s and 1930s (Garnham, 1945). In recent years, malaria situation has deteriorated with the disease becoming a serious Public Health problem in most parts of the country (Ministry of Health (MOH) Report, 1994). The disease has increased in many areas with development projects, especially those that impound water for agriculture and industry. In this connection epidemics have recently occurred in areas where previously the disease was unknown. For example, epidemics have been experienced in Uasin Gishu, Nandi and Kericho districts every year since 1988 and more recently in other new areas such as Kisii, Nyamira and Narok (MOH Report, 1994).

The worsening situation has a critical impact not only on people's health and survival but also on the country's economy and productivity. In this regard, there is evidence that in a textile factory in Eldoret, 53.2% of man-days loss is attributable to malaria (Some, 1992). At the same time the disease has become a major threat among tourists visiting Kenya's coastal towns where

malaria has tremendously increased the burden on the national health budget through hospital bed occupancy (Central Bureau of Statistic, 1984). In 1989 malaria was the leading cause of Out-patient attendance in the country, contributing to 26% of total morbidity in Kenya (Ministry of Health, 1992). The disease was ranked fourth as a cause of morbidity in infants and children, in 1978 (Central Bureau of Statistics, UNICEF, 1984).

Malaria control has always been an active component of the government's health programme. In the 1950s the global effort to achieve malaria eradication emphasized vector control through residual house spraying using DDT, Dieldrin and Fenitrothion, house screening, larviciding and environmental management (Fontaine *et al.*, 1978; Smith, 1966). It soon became clear that this goal was impossible to achieve and the emphasis has since shifted to control instead of eradication (WHO, 1969). Quinine was initially relied upon for treatment but was later replaced by effective synthetic compounds such as chloroquine during the 1950s (Rothe, 1956). Efforts to control malaria through chemotherapy has been greatly thwarted by increases in development of parasite resistance to cheap and easily available antimalarials such as chloroquine. The use of other alternative drugs and a return to quinine is recommended (Fogh *et al.*, 1979; Spencer *et al.*, 1983; Okello, 1984; O'Neil, 1987; Watkins *et al.*, 1987; Keuter, 1990; Oloo, 1991; Khan, 1991; Rukaria *et al.*, 1992).

5.1.1.2 Malaria situation in Mwea Tebere

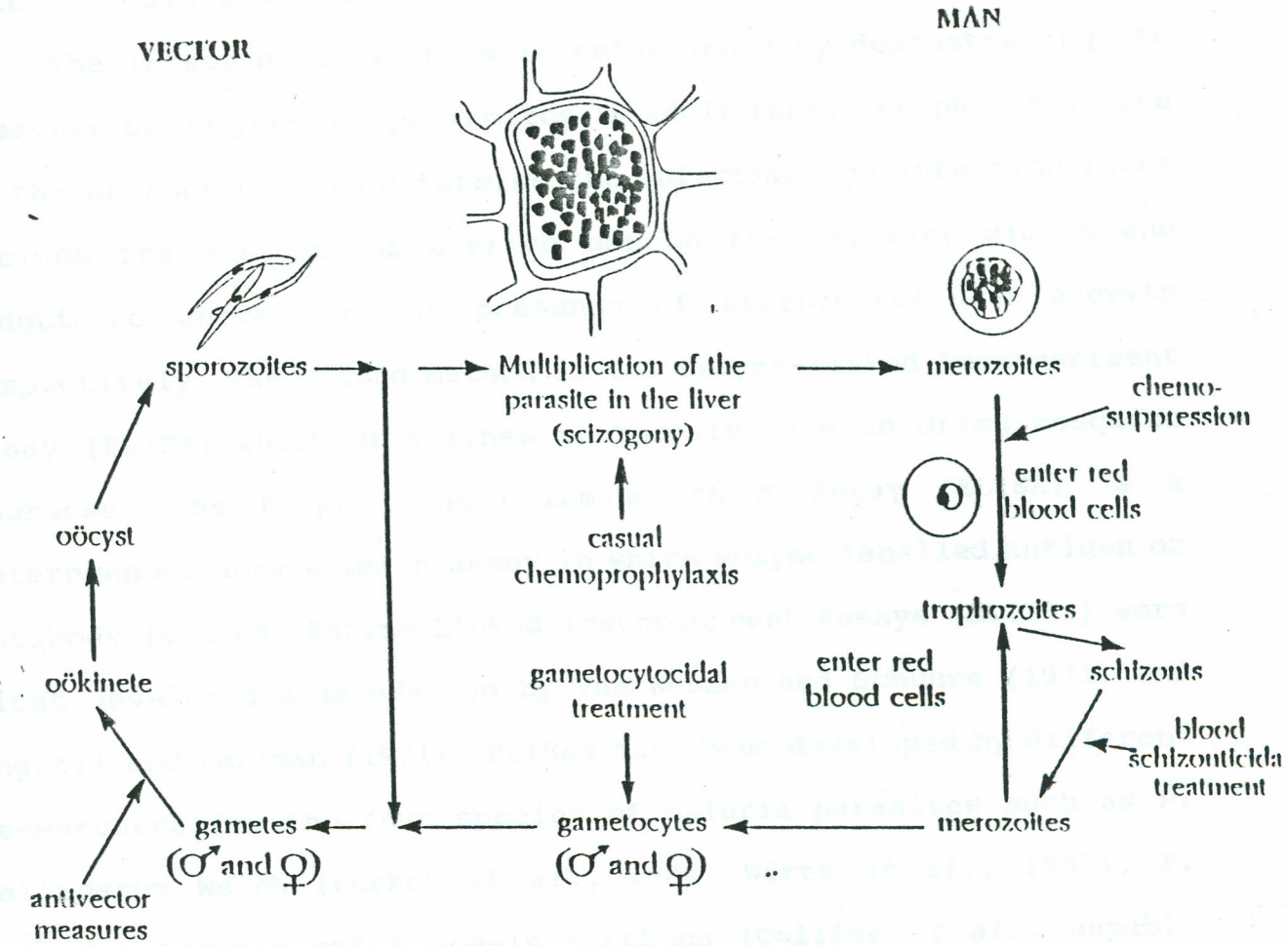
Mwea Tebere irrigation settlement scheme where these studies

were carried out (Fig. 1) lies within the Hypo- to Meso-endemic malaria zones and malaria prevalence is seasonal (Ministry of Health, 1992). Most of the areas surrounding it particularly the Mt. Kenya region are free from malaria. Although it is known that transmission of malaria occurs in Mwea Tebere, earlier studies have concentrated on the vector aspects and their potential in the transmission of the disease (Mukiama and Mwangi, 1989; Mutero, 1985; Ijumba *et al.*, 1990). In Mwea Tebere irrigation scheme, virtually no studies have been carried out to determine the endemicity of malaria in the area. The little information available is from reports from the Division of Vector Borne Diseases station in Kimbimbi. For this reason, it is important that baseline information on malaria endemicity is collected for use during future control of malaria in this locality. Comprehensive information on the malaria infections in both human as well as in mosquito populations is required simultaneously.

5.1.2 Malaria infection in the mosquitoes

Vectors of malaria parasite are usually incriminated by finding the developmental stages of the parasite such as sporozoites and oocysts which can be recovered through dissections from the salivary glands and the midgut respectively. Only mosquitoes of the genus *Anopheles* have been known to transmit *Plasmodium* species causing malaria in man. *Anopheles* vector is the definitive host because the sexual cycle of the malaria parasite occurs in the mosquito and man acts only as the intermediate host (Fig. 5). There are several factors which influence the sporozoite

Figure 5. **Schematic representation of malaria parasite's life cycle in the vector and human host.**


VECTOR
MAN
sporozoites
Multiplication of the parasite in the liver (schizogony)
merozoites
chemo-suppression
enter red blood cells
oöcyst
casual chemoprophylaxis
trophozoites
oökinete
gametocytocidal treatment
enter red blood cells
schizonts
blood schizonticida treatment
gametes (♂ and ♀)
gametocytes (♂ and ♀)
merozoites
antivector measures

rate. It varies from species to species of mosquitoes, locality, season and contact with man (Rossignol, 1988; Rosenberg *et al.*, 1990). The sporogonic cycle is influenced by temperature, and *Plasmodium* species. For example, at 24°C sporogony in *P. falciparum* takes 11 days and in *P. malariae* 21 days (Bruce-Chwatt, 1985).

The infection in vectors is established by demonstrating the presence of oocysts or sporozoites in adult female Anopheline. Some of the methods used to determine the infective and infection rates include the dissections carried out on the salivary glands and midgut to check for the presence of sporozoites and oocysts respectively. The second method is the Enzyme-linked Immunosorbent Assay (ELISA) which determines sporozoite rate on dried mosquito thoraces. The Enzyme Linked Immunosorbent Assay (ELISA) is a heterogenous enzyme immunoassay in which enzyme labelled antigen or antibody is used. Enzyme Linked Immunosorbent Assays (ELISAs) were first developed a decade ago by Van Weemen and Schuurs (1971) and Engvall and Perlman (1971). ELISAs have been developed by different researchers for the four species of malaria parasites such as *P. falciparum* Welch (Burkot *et al.*, 1984; Wirtz *et al.*, 1987), *P. malariae* Laveran and *P. ovale* Stephens (Collins *et al.*, unpubl. data). Practical application of the ELISA technique in malaria studies has been undertaken to assess the presence of sporozoites and the infection rate by several workers (Colins *et al.*, 1984; de Arruda *et al.*, 1986; Baker *et al.*, 1987; Beier *et al.*, 1987 and Wirtz *et al.*, 1987).

The main objective of the parasitological studies was to establish the malaria parasite prevalence rate in both human and

mosquito populations. Of particular interest was an understanding of the seasonal variations of the parasite rates according to temperature, rainfall patterns as well as rice cultivation practices.

5.2 MATERIALS AND METHODS

5.2.1 Malaria infection rates in the human population

5.2.1.1 Determination of prevalence of malaria by taking blood smears from asymptomatic people

During the first year of data collection, blood smears were made every month from individuals in the two study villages (Mbui Njeru and Mathangauta). The number of people sampled was based on those who presented themselves for examination and all age groups were taken into consideration. During the second year blood smears were collected from several other neighbouring villages to compare their status of malaria with that observed in Mbui Njeru and Mathangauta. Records of laboratory confirmed malaria cases from the local Kimbimbi Health Centre were compiled and compared to parasite prevalence rates in the villages in order to assess the frequency of clinical cases among parasite carriers. Slide smears were made from finger blood and stained with 2% giemsa. The blood slides were examined under a compound microscope at x100 magnification.

The estimate of malaria parasite numbers (MPN) was made by examining a thick smear where parasites were well-stained and could be clearly seen. The average number of trophozoites, gametocytes and schizonts was determined. Parasite numbers were recorded following the standard WHO procedure (WHO, 1969; Bruce-Chwatt,

1985).

5.2.1.2 Determination of Malaria infection rates in the vector mosquitoes

An. arabiensis, *An. funestus* and *An. pharoensis* collected from both indoor and outdoor resting sites had their salivary glands and midguts dissected out and examined for the presence of malaria parasites. A large sub-sample of the collected mosquitoes were also dried in a dessicator and transported to the Kenya Medical Research Laboratories in Nairobi for determination of the sporozoite rate by the Enzyme-Linked Immunosorbent Assay (ELISA). The latter method ensured that all the mosquitoes collected were tested for infections. A major advantage of ELISA is that the technique is applicable even when the mosquitoes are dry.

5.3 ANALYSIS OF DATA

The square root transformation was used for data on malaria prevalence rates in humans prior to analysis of variance. Data on the number of mosquitoes found infected with sporozoites was used to determine the sporozoite rate and chi-square test was carried out to determine if the differences were significant.

5.4 RESULTS

5.4.1 Malaria incidence in the human population

The age structure of the human population in the two study sites is summarized in table 5. In both Mbui Njeru and Mathangauta over 50% of the population consisted of adults. The total

Table 5. Age distribution of the population in Mbui Njeru and Mathangauta villages.

	Mbui Njeru		Mathangauta	
Age group	No. of people	%	No. of people	%
0-11 m	6	2.2	16	2.8
12-23 m	5	1.9	21	3.7
2-4 yrs	23	8.6	46	8.1
5-9 yrs	46	17.2	92	16.1
10-14 yrs	48	17.9	97	17.0
15+	140	52.2	298	52.3
Total	268	100	570	100

population was 268 and 570 in Mbui Njeru and Mathangauta respectively. There were 42 and 78 households in Mbui Njeru and Mathangauta respectively.

The results on the prevalence rate of malaria in the two study villages are summarized in tables 5.1, 5.2, 5.3 and figure 5.1. The prevalence in Mbui Njeru and Mathangauta was seasonal ranging from 0-6.5%. In Mbui Njeru the lowest prevalence (0%) recorded was in November, December 1989 and February, March 1990. In Mathangauta the lowest prevalence was recorded in September, December 1989 and January 1990. The general peak prevalence rate occurred in the month of July 1989 being 7.6% and 4% for both Mbui Njeru and Mathangauta village respectively. A second peak of 6.9% occurred in January 1990 in Mbui Njeru while Mathangauta had a second peak of 3% in November 1989 (Fig. 5.1). The overall malaria prevalence rate was found to be less than 8.7% for all age and sex groups in both Mbui Njeru and Mathangauta villages. The parasite prevalence rate for Mbui Njeru (Fig. 5.2) was significantly higher than for Mathangauta village for most part of the year ($F_{1,1}=12.6$; $P< 0.01$).

The predominant species of malaria parasite was *Plasmodium falciparum* Welch comprising 90% of all the infections recorded. The remaining infections which consisted of *P. malariae*. *P. ovale* and *P. vivax* were not recorded.

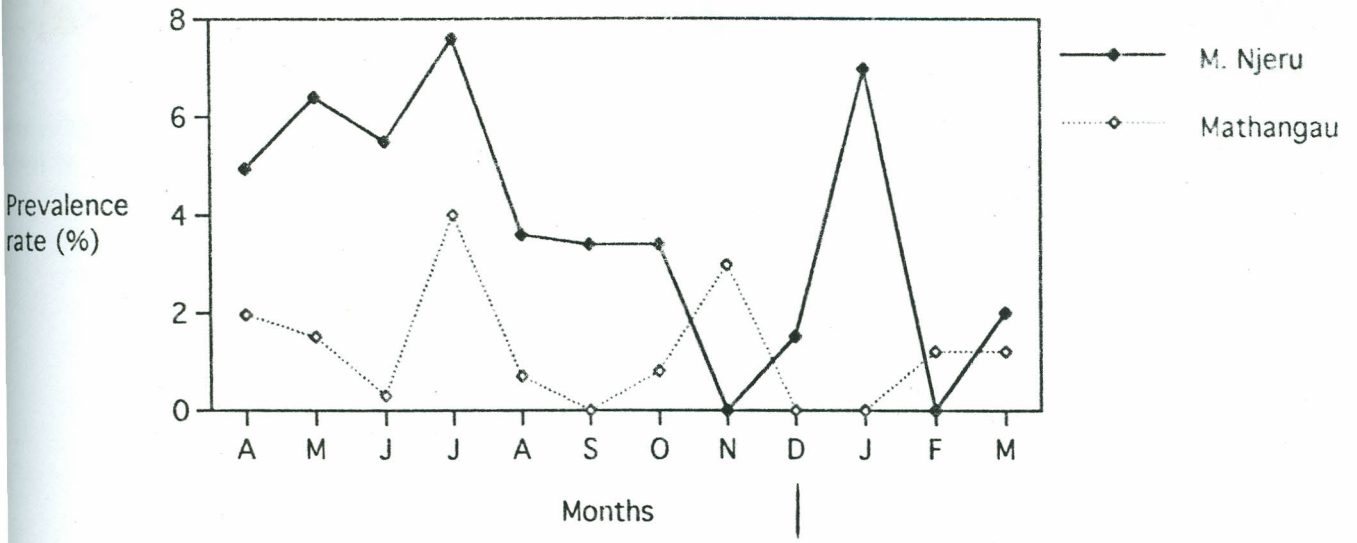
The results obtained from Kimbimbi health centre are shown in figure 5.2. They showed that in the health centre, the malaria prevalence rate ranged from 5% in August 1989 to 38% in January 1990. The peak prevalence observed in January was suprisingly observed when temperatures and rainfall were low (17.5 °C) and

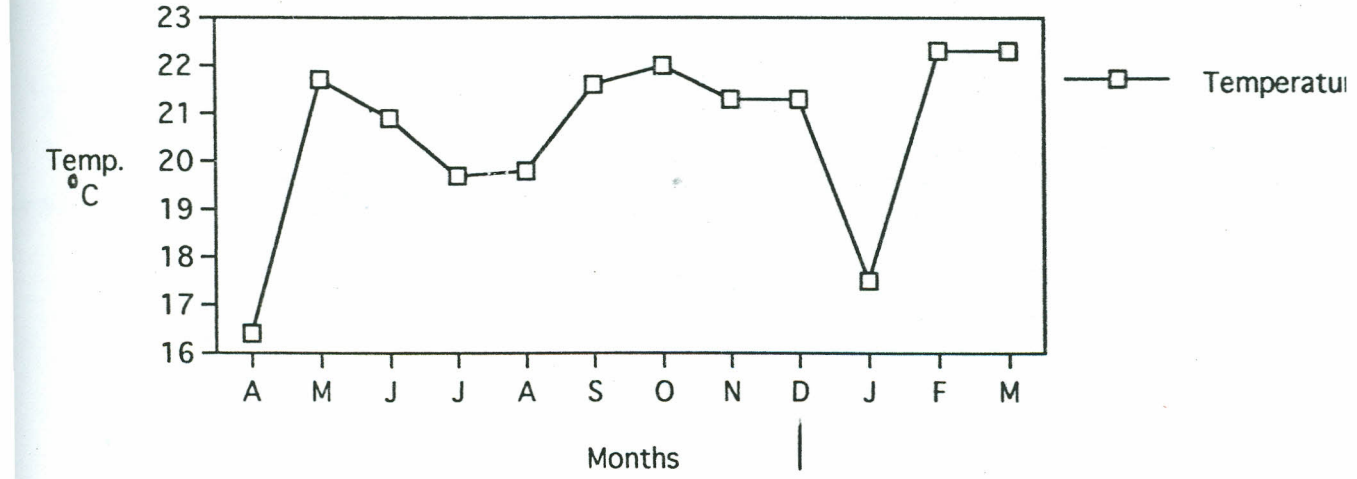
Table 5.1. Monthly and annual malaria prevalence rate in Mbui Njeru and Mathangauta villages.

	MBUI NJERU			MATHANGAUTA		
	Exam.	Pos.	Parasite rate %	Exam.	Pos.	Parasite rate %
April 1989	243	12	4.9	509	9	1.96
May	201	13	6.5	202	3	1.5
June	164	9	5.5	305	1	0.32
July	145	11	7.6	224	9	4.01
August	83	3	3.6	137	1	0.4
September	89	3	3.3	64	0	0
October	88	3	4.4	119	1	0.8
November	46	0	0	67	2	2.98
December	68	0	0	65	0	0
January 1990	43	3	6.9	33	0	0
February	15	0	0	83	1	1.2
March	54	0	0	83	1	1.2
Total	1239	54	42.7	1888	27	14.4
Average	103.3	4.5	4	157	2.3	1.2

No. Exam. = Number of persons examined
No. Pos. = Number of persons positive with malaria parasite
rate % = Proportion of persons harbouring malaria parasite

Figure 5.1. **Seasonal variation of malaria prevalence rate, temperature and rainfall in Mbui Njeru and Mathangauta villages.**


Prevalence rate (%)
8
6
4
2
0
A M J J A S O N D J F M
Months
M. Njeru
Mathangau


Temp. °C
23
22
21
20
19
18
17
16
A M J J A S O N D J F M
Months
Temperatu

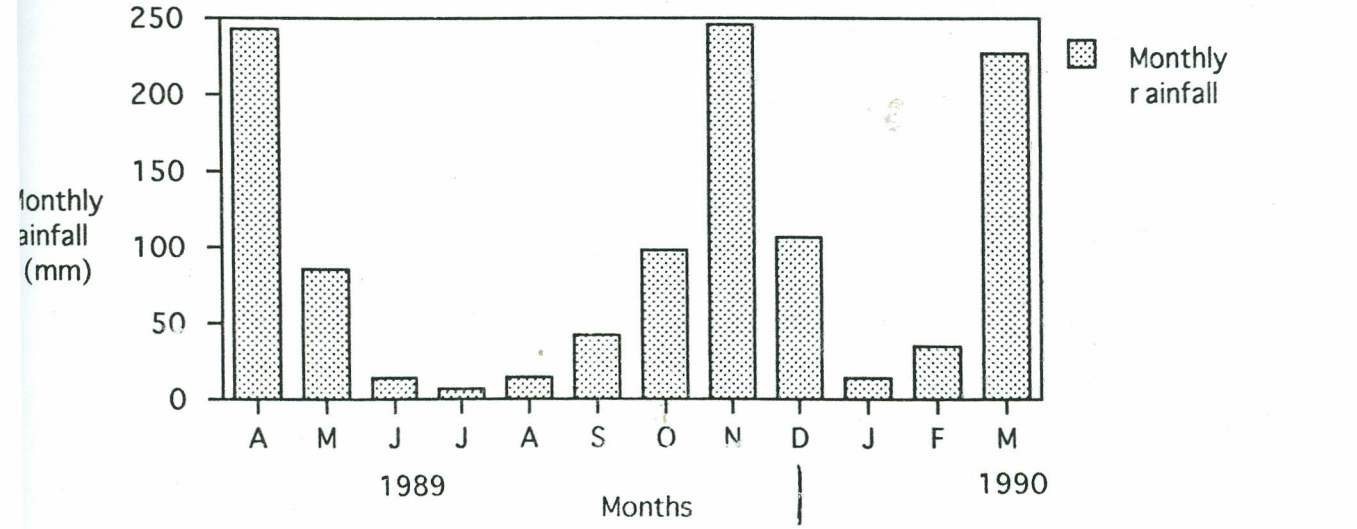
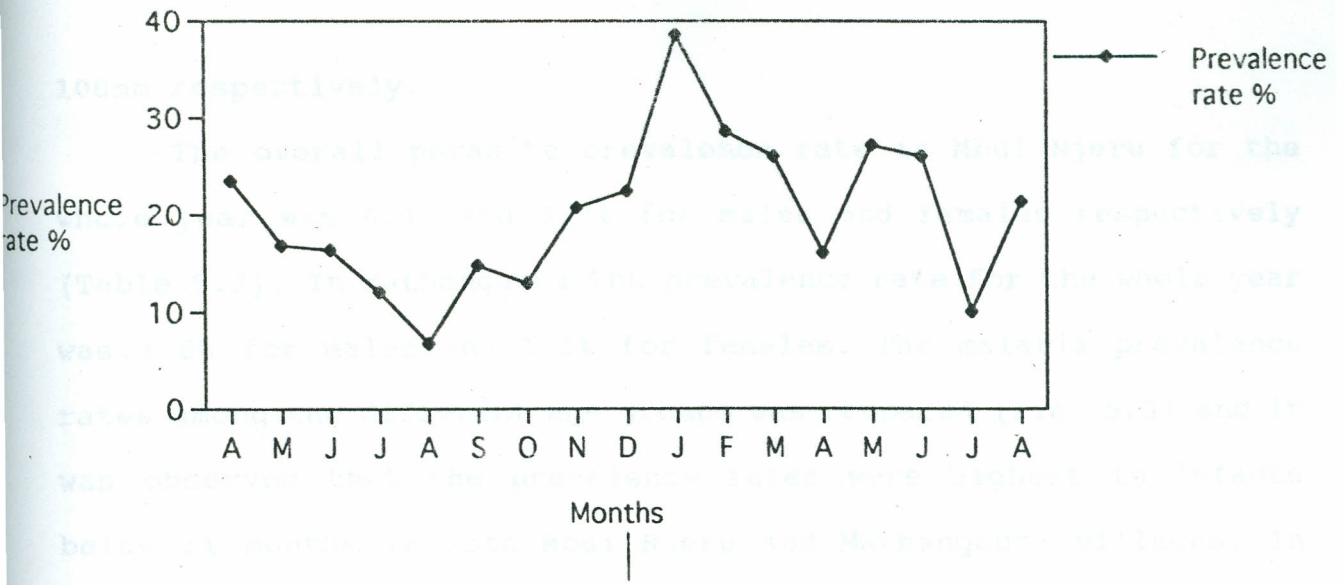
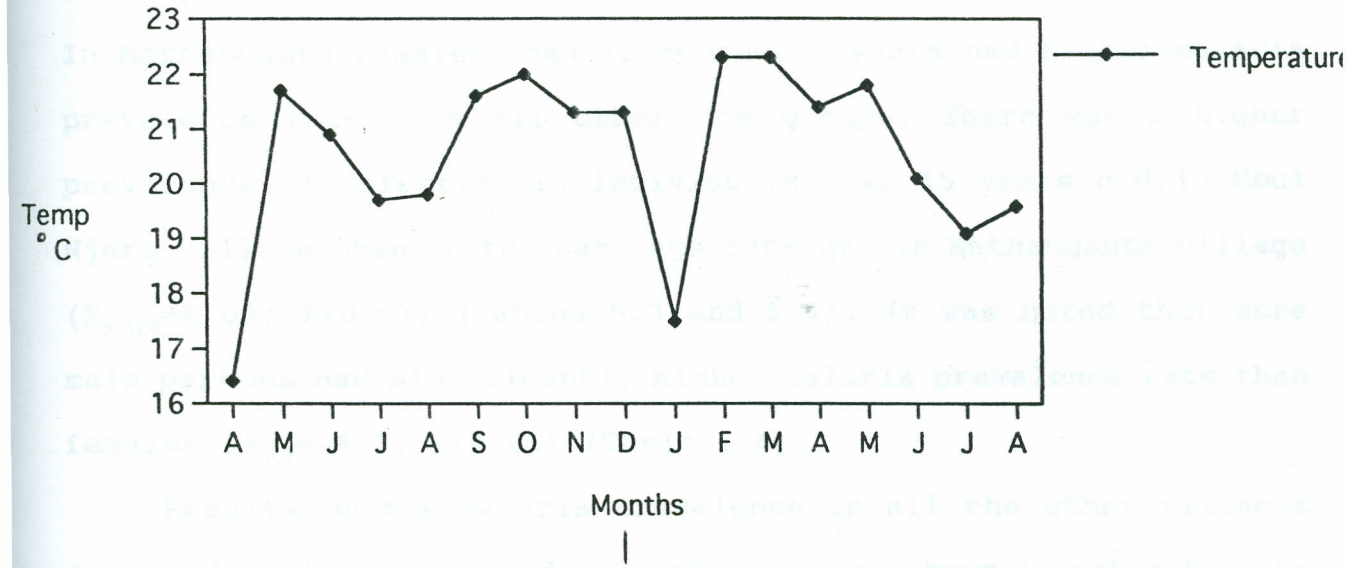
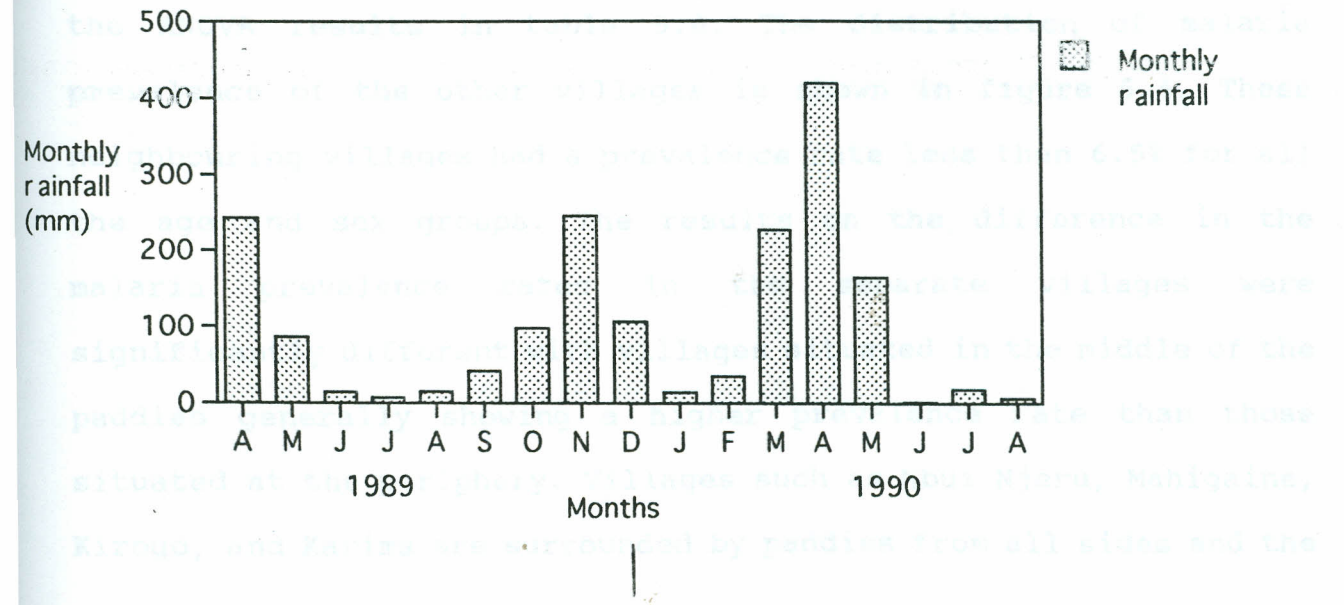

Monthly rainfall (mm)
250
200
150
100
50
0
A M J J A S O N D J F M
1989
Months
1990
Monthly r ainfall

Figure 5.2. **Seasonal variation of Malaria prevalence rate, temperature and rainfall at Kimbimbi health centr**


Prevalence rate %
40
30
20
10
0
A M J J A S O N D J F M A M J J A
Months
Prevalence rate %


Temp °C
23
22
21
20
19
18
17
16
A M J J A S O N D J F M A M J J A
Months
Temperature


Monthly rainfall (mm)
500
400
300
200
100
0
A M J J A S O N D J F M A M J J A
1989
1990
Months
Monthly rainfall

100mm respectively.

The overall parasite prevalence rate in Mbui Njeru for the whole year was 6.3% and 3.7% for males and females respectively (Table 5.2). In Mathangauta the prevalence rate for the whole year was 1.6% for males and 1.1% for females. The malaria prevalence rates among the different age groups was compared (Fig. 5.3) and it was observed that the prevalence rates were highest in infants below 11 months in both Mbui Njeru and Mathangauta villages. In Mbui Njeru, males had higher malaria prevalence rate than females. In Mathangauta females aged 12 months, 4 years had higher malaria prevalence rate than all other age groups. There was a higher prevalence of infection in individuals over 15 years old in Mbui Njeru village than in the same age category in Mathangauta village ($F_{5,120}=4.02$; $P<0.01$) (Tables 5.3 and 5.4). It was noted that more male persons had significantly higher malaria prevalence rate than females ($F_{1,1}= 6.3$; $P<0.01$) (Table 5.4).

Results on the malaria prevalence in all the other villages screened during the second year of study are shown in table 5.5 and the ANOVA results in table 5.6. The distribution of malaria prevalence of the other villages is shown in figure 5.4. These neighbouring villages had a prevalence rate less than 6.5% for all the age and sex groups. The results on the difference in the malaria prevalence rates in the separate villages were significantly different with villages situated in the middle of the paddies generally showing a higher prevalence rate than those situated at the periphery. Villages such as Mbui Njeru, Mahigaine, Kirogo, and Karima are surrounded by paddies from all sides and the

Table 5.2. **Summary of the monthly Malaria prevalence distribution according to sex and age in Mbui Njeru collected from April 1989 to March 1990.**

	MALES			FEMALES		
Age Group	No. Examined*	No. +ve	Parasite rate%	No. Examined*	No. +ve	Parasite rate %
0-11 m	23	2	8.7	11	0	0
12-23 m	21	0	0	8	0	0
2-4 yrs	62	3	4.8	56	1	1.8
5-9 yrs	121	9	7.4	128	7	5.5
10-14 yrs	155	11	7.1	134	6	4.5
15+	238	14	5.9	280	9	3.2
Total	620	39	6.3	617	23	3.7

Table 5.3. **A Summary of the monthly Malaria prevalence distribution according to sex and age in Mathangauta collected from April 1989 to March 1990.**

	MALES			FEMALES		
Age Group	No. Examined*	No. Pos.	Parasite rate %	No. Examined*	No. Pos.	Parasite rate %
0-11 m	23	1	4.3	25	0	0
12-23 m	34	1	2.9	27	1	3.7
2-4 yrs	95	1	1.1	111	4	3.6
5-9 yrs	200	7	3.5	190	1	0.5
10-14 yrs	168	2	1.2	174	1	0.6
15+	420	3	0.7	443	4	0.9
Total	940	15	1.6	970*	11	1.1

* Shows that the number examined is higher than the population of the villages. This is a total of persons examined repeatedly over a period of one year.

Table 5.4. Malaria prevalence in Mbui Njeru and Mathangauta villages.

Village	n	Total Examined	No. Positive	Parasite rate %
Mbui Njeru	12	1237	62	5.0
Mathangauta	12	1910	26	1.4

Table 5.4a. ANOVA table for malaria prevalence in Mbui Njeru and Mathangauta.

Sources of variation	SS	df	MSS	F	Sig.
Main-Plot analysis					
Sex	6.898	1	6.898	6.265	**
Village	13.903	1	13.903	12.628	**
Error (a)	1.101	1	1.101		
Subplot analysis					
Months	54.697	11	4.972	6.254	**
Village x months	12.123	11	1.102	1.386	NS
Error (b)	17.493	22	0.795		
Sub-sub plot analysis					
Age	20.126	5	4.025	5.808	**
Village x age	13.931	5	2.786	4.020	**
Month x age	42.859	55	0.779	1.124	NS
Village x Month x age	29.416	55	0.535	0.772	NS
Error (c)	83.217	120	0.693		
Total	295.764	287			

n = Number of times collections were made
SS = Sums of squares
df = Degrees of Freedom
MSS = Mean sums of squares
F = Variance ratio
Sig = Significance
** = Highly significant (P<0.01)
NS = Not significant (P>0.01)

Table 5.5. Malaria prevalence distribution in other selected villages within Mwea Irrigation settlement Scheme.

Village	Males			Females		
	No. Examined	No. Pos.	Parasite Rate %	No. Examined	No. Pos.	Parasite Rate %
Thiba*	215	7	3.3	295	3	1
Matandara**	59	1	1.7	36	0	0
Haraka	170	0	0	163	6	3.7
Mahigaini*	186	7	3.8	206	7	3.4
Karira*	155	1	0.6	252	3	1.2
Matandara**	68	1	1.5	99	2	2
Murubara*	190	2	1.1	210	4	1.9
Karima*	92	6	6.5	169	7	4.1
Kirogo*	244	8	3.3	202	5	2.5
Total	1379	31	2.2	1632	33	2.02

Blood smear survey carried out for the following months:

* 1 month in 1990
** 2 months in 1990

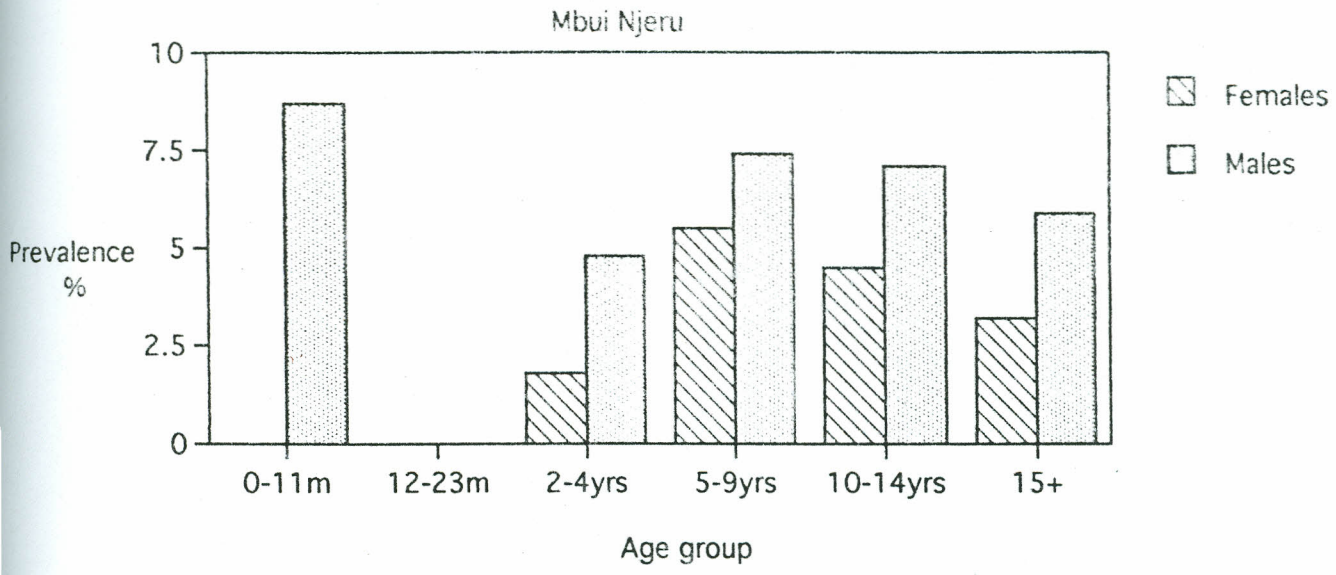
Table 5.6. ANOVA table of malaria prevalence rate in the human population in other villages in Mwea Tebere irrigation scheme.

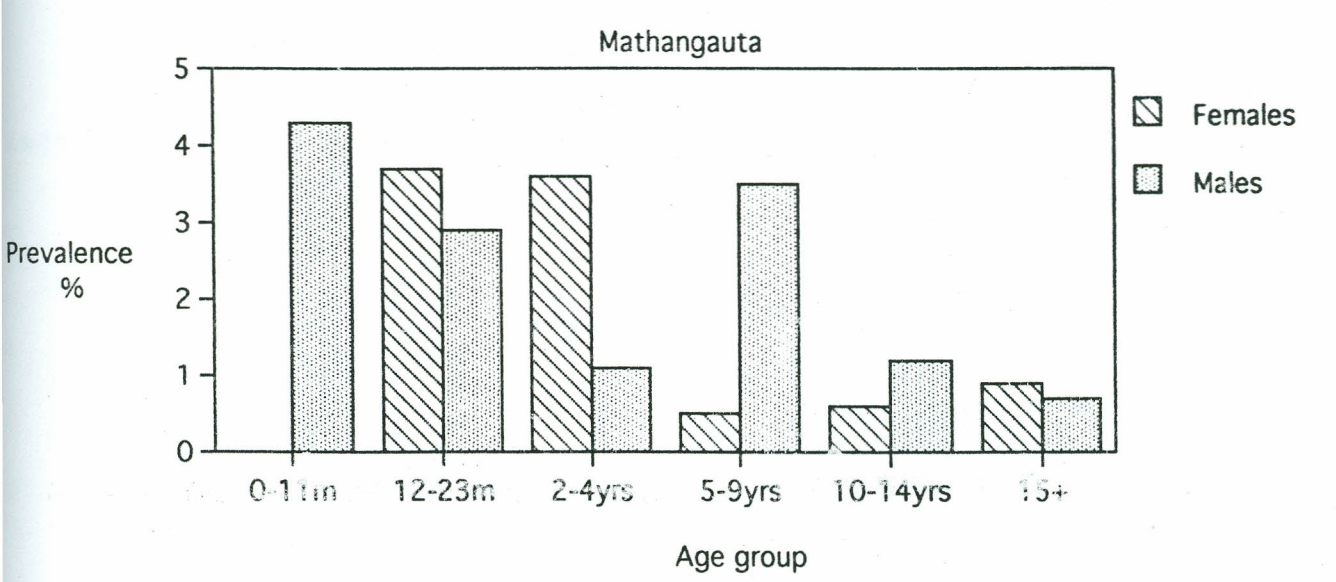
	MALES			FEMALES		
n	No. examined	No. +ve	Parasite rate (%)	No. examined	No. +ve	Parasite rate (%)
9	1379	31	2.2	1632	33	2.02

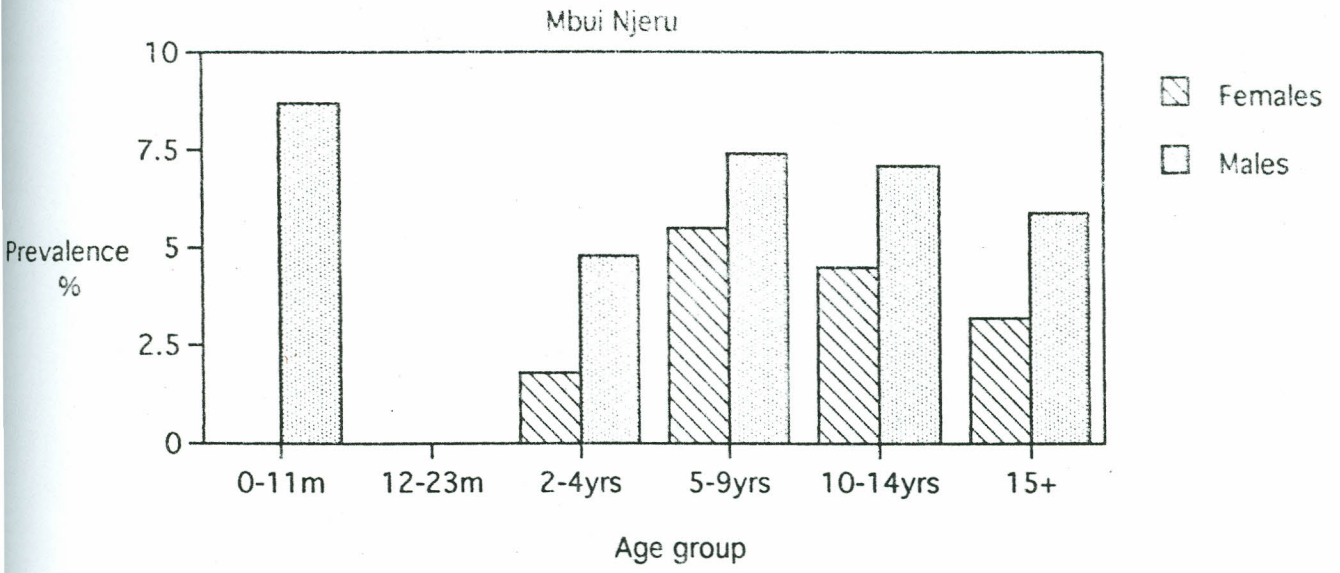
Sources of variation	SS	df	MSS	F	Sig.
Main plot analysis					
Age groups	10.456	5	2.091	4.216	NS
Sex	0.084	1	0.084	0.169	
Error (a)	2.479	5	0.496		
Sub-plot analysis					
Village	6.266	1	6.266	10.323	
Village x Sex	6.116	1	6.116	10.076	
Error (b)	27.914	46	0.607		
Total	53.315	59			

SS = Sum of Squares
df = Degrees of freedom
MSS = Mean Sum of Squares
F = Variance ratio
Sig.= Significance
NS = Not significant (P>0.01)
** = Highly significant (P<0.01)

Figure 5.3. **Distribution of malaria parasite prevalence rate according to age and sex in Mbui Njeru and Mathangauta villages.**


Mbui Njeru
10
7.5
5
2.5
0
Prevalence %
0-11m
12-23m
2-4yrs
5-9yrs
10-14yrs
15+
Age group
Females
Males


Mathangauta
5
4
3
2
1
0
Prevalence %
0-11m
12-23m
2-4yrs
5-9yrs
10-14yrs
15+
Age group
Females
Males


Mbui Njeru
10
7.5
5
2.5
0
Prevalence %
0-11m
12-23m
2-4yrs
5-9yrs
10-14yrs
15+
Age group
Females
Males

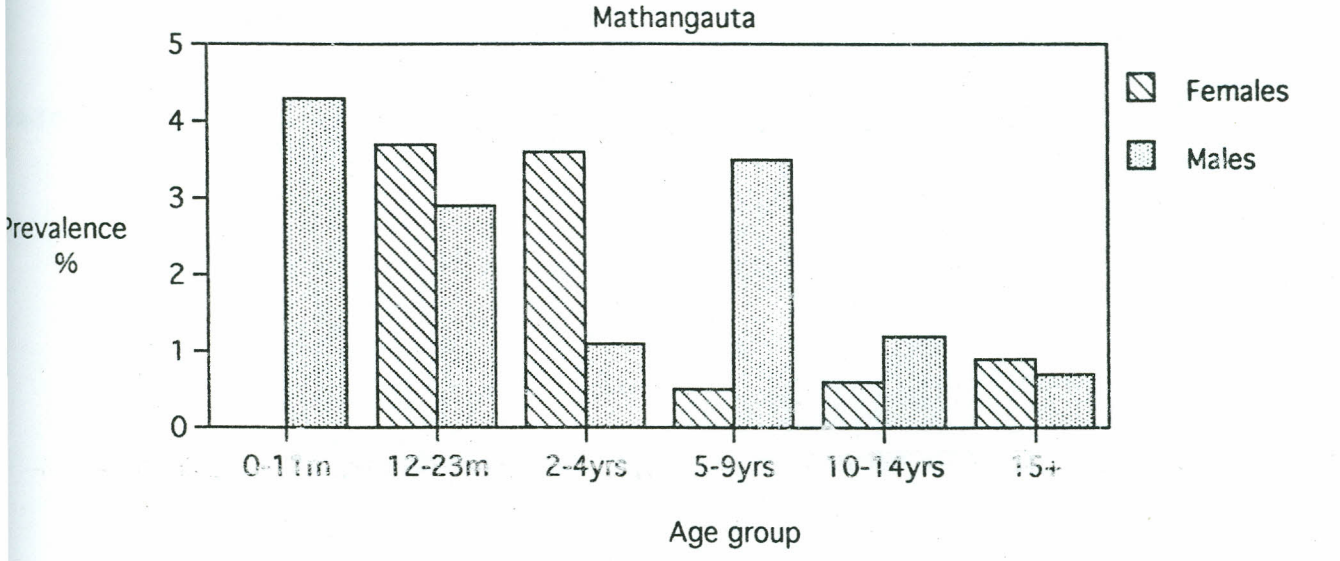
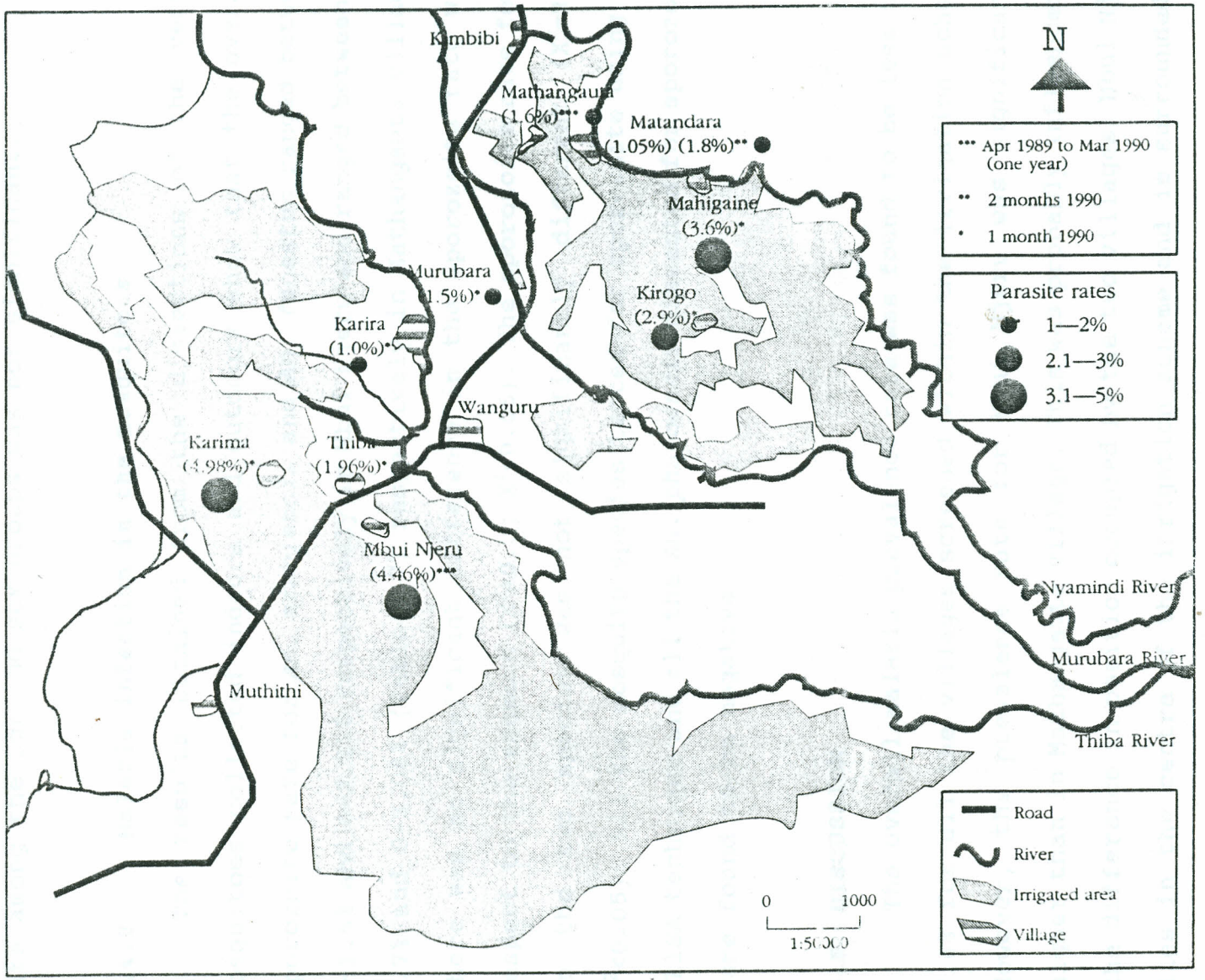

Mathangauta
5
4
3
2
1
0
Prevalence %
0-11m
12-23m
2-4yrs
5-9yrs
10-14yrs
15+
Age group
Females
Males

Figure 5.4. **The malaria parasite prevalence rate in selected villages of Mwea Tebere Irrigation Scheme.**


Kimbibi
Mathangauna
(1.6%)***
Matandara
(1.05%) (1.8%)**
Mahigaine
(3.6%)*
Murubara
(1.5%)*
Kirogo
(2.9%)*
Karira
(1.0%)*
Wanguru
Karima
(4.98%)*
Thiba
(1.96%)*
Mbui Njeru
(4.46%)***
Muthithi
Nyamindi River
Murubara River
Thiba River
N
*** Apr 1989 to Mar 1990 (one year)
** 2 months 1990
* 1 month 1990
Parasite rates
1—2%
2.1—3%
3.1—5%
Road
River
Irrigated area
Village
0
1000
1:50 000

malaria prevalence rate was over 3% in all the cases while villages such as Mathangauta, Murubara, Thiba, Matandara and Karira which are situated at the periphery of the paddies had malaria prevalence rate less than 2%. The difference observed in malaria prevalence rate among the age and sex groups was not significant.

5.4.2 Malaria infection in the mosquitoes

The results obtained from the dissections of the vector mosquitoes collected indoors and outdoors show that the overall sporozoite rate for *An. arabiensis* and *An. funestus* ranged between 0-1.6% and 0-2.22% respectively in Mbui Njeru and ranged between 0-1.7% and 0-3.08% (Table 5.7) respectively in Mathangauta village. There was no significant difference in the sporozoite rate with respect to the seasons (X^2=0.3; X^2<0.05). The sporozoite rate found in the two species was not significantly different (X^2=2.3; X^2<0.05). All the mosquito species tested for sporozoite using the ELISA technique and all the *An. pharoensis* dissected for sporozoite were found to be negative.

5.5 DISCUSSION

The overall malaria prevalence rate was found to be less than 7.6% for all the villages screened within the irrigation scheme. However, the prevalence rate for Mbui Njeru was significantly higher than in Mathangauta village. This was probably influenced by the difference in position occupied by the two villages. Mbui Njeru lies in the centre of the irrigation scheme and is surrounded by flooded paddies from all sides while Mathangauta lies at the

Table 5.7. The sporozoite rate of Anopheline mosquito species in Mbui Njeru and Mathangauta

A. Mbui Njeru

Season	Site	Species	No. dissected	No. +ve	Sporozoite rate (%)
Dry (June-Sept)	Indoor	*An. arabiensis*	3729	10	0.27
		An. funestus	187	0	0
	Outdoor	*An. arabiensis*	652	4	0.6
		An. funestus	66	0	0
Short rains (Nov-Dec)	Indoor	*An. arabiensis*	1588	4	0.3
		An. funestus	45	1	2.22
	Outdoor	*An. arabiensis*	133	0	0
		An. funestus	1	0	0
Long rains (Mar-May)	Indoor	*An. arabiensis*	1142	2	0.18
		An. funestus	45	1	2.22
	Outdoor	*An. arabiensis*	58	0	0
		An. funestus	3	0	0

B. Mathangauta

Season	Site	Species	No. dissected	No. +ve	Sporozoite Rate (%)
Dry (June-Sept.)	Indoor	*An. arabiensis*	713	1	0.14
		An. funestus	931	4	0.4
	Outdoor	*An. arabiensis*	29	0	0
		An. funestus	60	1	1.67
Short rains (Nov-Dec)	Indoor	*An. arabiensis*	636	1	0.16
		An. funestus	283	2	0.71
	Outdoor	*An. arabiensis*	137	0	0
		An. funestus	14	0	0
Long rains (Mar-May)	Indoor	*An. arabiensis*	129	2	1.55
		An. funestus	65	2	3.08
	Outdoor	*An. arabiensis*	60	1	1.67
		An. funestus	4	0	0

periphery and is only adjacent to the paddies on one side. The low infection rate in Mathangauta underscores the importance of situating villages far away from mosquito breeding sites. This observation was in agreement with the results from other villages. For example, in villages situated in the centre of the paddies had a higher malaria prevalence rates than those situated at the periphery.

Another observation that could probably be the reason for higher prevalence rate in Mbui Njeru is because during the rice growing cycle, Mbui Njeru is flooded much earlier from the month of March each year until December for approximately 10 months and therefore provides suitable mosquito breeding sites for longer duration. In Mathangauta the paddies are flooded much later from July to December for approximately 6 months and therefore the period for mosquito breeding is shortened.

It was noted that the prevalence rate of malaria in males was higher compared to females. This has also been reported by other workers (Seroney *et al.*, 1987; Mutero *et al.*, 1992). Although the explanation to this observation is not clear, it could probably be due to the social and cultural behaviour of males who stay outdoors for longer duration in the evenings than females and are thus exposed to transmission for a longer period. The influence of sex on parasitic diseases have been studied by several workers. Goble and Konopka (1973) reported that the incidence of malaria is the same in both sexes but females especially during pregnancy, suffer more serious manifestations.

Transmission can be effectively maintained either indoors or

outdoors because the vectors are probably endophagic or exophagic. The results observed in the previous studies in Ahero (DVBD Report, 1992) were obtained in an area where the vectors *An. gambiae s.s.* were endophagic. In this study the vector *An. arabiensis* were predominantly exophagic and endophilic (Details in Chapter 4).

Continual transmission within the community allows malaria to be firmly established within the population living there. When a person is infected with malaria, the body begins to develop immunity against the malaria parasite and this offers protection against mortality. In malaria endemic areas the pattern of infection shows a decline in the infection rate with age (WHO, 1975), reflecting increased immunity in older people. In this study the infection rates were higher in the age group above five years old with the exception of Mbui Njeru where the infection rate in those below 11m old was 8.7%. Lack of increased immunity with age in Mbui Njeru illustrated by a lack of decline of infection rates in older people probably suggested that settlers in the village had moved there more recently than in Mathangauta. The data must be interpreted with caution since inability to undertake proportionate sampling of the population on certain occassions may have introduced a certain degree of error in the observed infection profiles.

The influence of geographical location on the pattern of endemicity of malaria in the different irrigation schemes was compared. Generally the malaria parasite prevalence rate observed in both Mbui Njeru and Mathangauta was less than 8.7% in all the age and sex groups. Further investigations to compare malaria

parasite prevalence rate observed in Mbui Njeru and Mathangauta with other cluster villages situated in the irrigation scheme also showed that the prevalence rate was less than 6.5% in males and 4.1% in females respectively for all age groups. This was rather low in comparison to other irrigation schemes in Kenya. For example, the prevalence rate in the irrigation scheme in Kano plains, Western Kenya, ranges between 48-63% in different villages (DVBD Report, 1992); (Appendix 5.8). It therefore shows that the situation of malaria differs in irrigation schemes situated in different geographical zones. The difference is probably influenced by the presence of large human populations infected by malaria in the Kano plains while in Mwea Tebere the surrounding area at the foothills of Mount Kenya consists of a large population free from malaria.

Studies on the infective rate of *An. arabiensis* in Mbui Njeru showed that the sporozoite rate ranged between 0.2-0.3% and for *An. funestus* 0-2.2% and 0% for indoor and outdoor collections respectively. In Mathangauta the sporozoite rate for *An. arabiensis* ranged from 0.1-1.6% and for *An. funestus* 0.4-3.08% and 0-1.7% for indoor and outdoor collections respectively. These observations show that the sporozoite rates were low both during the long and short rains as well as dry season. This was due to the fact that the vector was *An. arabiensis*, whose vectorial efficiency is lower than *An. gambiae* s.s. (Taylor *et al.*, 1990). Among the sibling species complex, the vectorial efficiency varies with *An. gambiae* s.s. being the most efficient vector and *An. quadriannulatus* the worst vector. The vectorial capacity of all the other sibling

species falls somewhere between the two extremes (Coluzzi and Sabatini, 1967; Colluzzi *et al.*, 1979; Taylor *et al.*, 1990). *An. arabiensis* is an opportunistic vector with a wide host range, therefore it relies on the nearest available host. In this case the vector preffered bovid as opposed to human hosts (see Chapter 4). In this study, cows tethered outdoors near the dwellings acted as the immediate host for vector mosquitoes emerging from the paddies. They first take their blood meal then seek suitable resting sites indoors. Earlier observations have shown that even after feeding outdoors on bovid they entered houses to rest. Other workers also reported low sporozoite rates. For example, Ijumba *et al.*, (1990) while working in one of the villages in the Mwea irrigation scheme, Karima reported sporozoite rates ranging from 0% during the short rains and 1.2-1.6% in *An. arabiensis*, *An. funestus* and *An. pharoensis* during the long rains and he attributed this observation on the low human blood index of the vector species and low survival rate.

The ELISA technique is a sensitive tool in detecting the presence of *Plasmodium* specific circumsporozoite (Cs) antigen. In this study all the mosquitoes tested for determination of sporozoites were negative. This confirms the low sporozoite rate observed. A look at the sporozoite rates of *An. arabiensis* has been done by several workers in different parts of Kenya; for example, Joshi, *et al.* (1978) reported 5%; Highton *et al.*, (1979) reported 0.33% in Kisumu and Ijumba *et al.*, (1990) reported 1.24% in Karima (Mwea Tebere). The observations reflect local differences in the sporozoite rates for *An. arabiensis* in several disease foci

contributing to different transmission patterns which may require different control strategies.

CHAPTER 6

6.1 GENERAL DISCUSSION

The relationship between the presence of a large number of anopheles vector mosquitoes and the high incidence of malaria in endemic areas is usually so close that it is regarded as one of the most firmly established facts in malariology. On the other hand, the seasonal periodicity of malaria is essentially attributable to seasonal variations in the prevalence of the vector-mosquito. The endemicity of malaria corresponds to the distribution of the mosquito vectors. In Kenya where transmission of malaria occurs throughout the year, there are persistently high numbers of mosquito vectors.

Results obtained from these studies on the population of mosquitoes in the area studied show that there are many factors which influence the efficiency of a vector to transmit malaria. The densities of vector mosquitoes were regulated by rainfall patterns and rice growing cycles. The mosquitoes increased gradually after the rains and the increase was further sustained by the presence of flooded paddies leading to numbers large enough to maintain the transmission of malaria in the areas studied. It was also observed that the results of the incidence of malaria did not show positive correlation between mosquito numbers and malaria prevalence. Prevalence rates peaked in January and July when *An. arabiensis* mosquito density was lowest. This may have probably been due to a number of reasons such as 1) *An. arabiensis* used cattle as their main host instead of humans; 2) *An. funestus* may probably be the main vector of malaria in Mwea Tebere instead of *An. arabiensis* and

3) survival rate during the peak was much lower than at other times possibly due to fewer adults due to lower reserves at emergence from a crowded breeding site.

Anopheles arabiensis was the predominant species (50-98%) throughout the year (Fig. 3) in Mbui Njeru village. On the other hand in Mathangauta *An. arabiensis* and *An. funestus* peaked at alternate times because it had different ecological zone from the one occupied by Mbui Njeru in relation to irrigated land. As the numbers of *An. gambiae* increased that of *An. funestus* decreased and vice-versa. This means that there is always a vector mosquito present to sustain malaria transmission in the absence of the other.

The rice growing cycle also had an influence on the diversity and density of the various mosquito species. Generally, flooding of the paddies increased the numbers of mosquitoes while draining of the water from the paddies decreased their numbers. While preparation of the nurseries and transplantation of rice seedlings favoured the breeding of *An. arabiensis*, draining of paddies and harvesting period favoured the breeding of *An. funestus*. This was as a result of water from the paddies which was chanelled into the canals. These canals had dense vegetation capable of creating suitable breeding sites for *An. funestus*. Farmers in Mathangauta village also engage in cultivation of other agricultural produce such as French beans and tomatoes which require preparation of furrow irrigation. These furrows increase stagnant water areas and bring about ecological changes such as numerous channels that probably support the breeding of a variety of vector mosquitoes.

The difference in Mbui Njeru village concerning water management is that once water is drained from the paddies it is chanelled into the main canals characterised by fast flowing water.

It was observed that *An. arabiensis* resting indoors were mostly fully fed after feeding outdoors showing that they have endophilic behaviour. This can be exploited in regard to vector mosquito control using residual house spraying or the more recent use of impregnated fabrics indoors.

During these studies it was demonstrated that the sporozoite infective rate in the vector mosquitoes was low (1%). Although *An. funestus* recorded were fewer than *An. arabiensis*, they were efficient vectors. The malaria parasite rate in the human population was also low (<8.7%) in all age and sex groups from all the villages that were screened. These studies therefore strongly suggest that despite the favourable conditions that existed for malaria transmission to occur, there were some factors inhibiting the vector mosquitoes from being efficient. These findings are in aggreement with Burkot's view that "malaria is a complex system in which transmission depends on a multitude of factors of which vector density may not be the most important and lays emphasis on the factors influencing host selection" (Burkot, 1988). Host selection by vectors is the result of a combination of intrinsic preferences modulated by extrinsic factors. The likelihood of a mosquito feeding on humans depends both on intrinsic host preference and on host availability.

In this case the vectors fed on bovine hosts because these were readily available. These results can be used to design further

investigations on the effects of Zoophily on malaria transmission i.e. to determine the difference in the transmission of malaria among occupants of houses with and without cattle. Generally, there are several ways in which changing numbers of cows will affect human inoculation rates by the vectors. These include the number of insects emerging, the proportion feeding on humans, the survival of the vector and lastly, the animals that can act as a source of infection. These factors operate simultaneously, resulting in a complex interplay between changing numbers of cows and changing potential for transmission of human disease.

Evidence of the influence of irrigation schemes on the density of mosquitoes has been reported by several workers in other countries and also in Kenya (Surtees *et al.*, 1970; Oomen *et al.*, 1979). Ijumba *et al.*, (1990) reported that the sporozoite rate among the vector mosquitoes in Mwea Tebere was low and attributed this to the zoophilic behaviour of the vectors. However, the results obtained from this study revealed for the first time in Kenya the role of zoophily on malaria prevalence. Thus, despite the high numbers of mosquito vectors observed, their preference for bovine host reduced their vectorial capacity.

6.2 GENERAL CONCLUSIONS

1. The relative density of *An. arabiensis* and *An. funestus* occurring in a particular village within an irrigation scheme is dependent on the location of the village in relation to the irrigated paddies. Those villages surrounded by flooded paddies from all sides had higher numbers of

mosquitoes than those encroached by paddies from only one side.

2. *An. arabiensis* occurred in relatively high numbers compared to other Anopheline species in Mwea Tebere.

3. The monthly variation of *An. arabiensis* was regulated by the rainfall patterns and rice growing activities with the peak occurring during the dry season in the month of September. During the rainy season there were numerous ground pools which encouraged *An. arabiensis* breeding during rice growing activities. Preparation of nurseries encouraged mosquito breeding.

4. The monthly variation of *An. funestus* was influenced by the rice growing cycle and there were two high and low peaks which occurred in January (High) and June/July (low) respectively. Water from the paddies is channelled into drainage and feeder canals. These usually have uncleared vegetation and provide suitable breeding sites for *An. funestus*.

5. *An. arabiensis* preferred to rest more indoors than outdoors implying that their control can be achieved by residual house spray.

6. Sufficient relative numbers of mosquitoes were sampled using the available sampling tools such as the aspirator, pyrethrum

spray catch and the CDC light trap. Mosquitoes collected using the aspirator method were alive and thus facilitated several observations to be carried out on an individual specimen. Mosquitoes collected by the pyrethrum spray collection may probably be dead but the method can be relied on to provide information on absolute densities.

7. *An. arabiensis* and *An. funestus* were the main vectors of *Plasmodium* in Mwea. With regard to efficiency in the transmission of malaria parasite by the mosquitoes, *An. funestus* was a better vector than *An. arabiensis*.

8. *An. arabiensis* was observed to be an opportunistic vector feeding facultatively on either human hosts or livestock.

9. Malaria prevalence rate which was mainly caused by *Plasmodium falciparum* was very low in most of the villages in the irrigation scheme. This low incidence of malaria was attributed to Zooprophylaxis.

6.3 RECOMMENDATIONS FOR FUTURE STUDIES

Although this study was completed it was not possible to look at all aspects of the behaviour and ecology of *An. arabiensis*. There is need for long term monitoring to countercheck if there will be changes regarding what has been observed. Therefore continous surveillance of *An. arabiensis* and malaria should be encouraged and supported as mentioned below.

1. These studies suggested that there may have been ecological competition between *An. arabiensis* and *An. funestus* in Mathangauta village only. More detailed studies should therefore be carried out to determine if this is the case.

2. These studies further showed the influence of zoophily on the incidence of malaria. There is need to determine how best to exploit the zoophilic method in malaria control by studying the optimal numbers of cows required to have an impact on malaria incidence especially in areas where the vector is *An. arabiensis* and apply it through community participation.

3. There is need to further investigate the strategy of the optimum number of cows required near houses that may have an influence on the incidence of malaria. Such investigations would indicate the importance of identifying *An. gambiae* s.l. upto the sibling species level because before a control programme is initiated, results of these taxonomic studies would assist the planners in making specific decisions on which control method to use.

4. Further studies should be carried out to determine the factors which make cattle attractive to *An. arabiensis*. Such studies have been carried out with tsetse flies and their control through the use of attractants. The same could possibly be applied in the case of *An. arabiensis*.

5. In addition, further studies should be carried out to see the

malaria situation in houses with cattle and those without.

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Appendix 1. Distribution of *An. arabiensis* in Mbui Njeru and Mathangauta villages by sex

	Mbui Njeru				Mathangauta			
	Indoors		Outdoors		Indoors		Outdoors	
	F	M	F	M	F	M	F	M
Apr '89	232	52	18	1	13	0	10	0
May	255	79	28	10	37	6	47	27
Jun	379	139	37	15	28	15	5	0
Jul	280	92	38	9	11	11	2	1
Aug	668	369	97	63	34	15	4	2
Sep	2914	1711	365	210	433	204	9	1
Oct	1853	940	242	220	564	281	37	19
Nov	364	228	71	38	239	95	76	51
Dec	167	59	8	3	64	47	25	35
Jan	348	39	1	0	0	1	1	0
Feb	238	47	6	0	2	0	0	8
Mar	138	24	1	0	29	20	3	0
Apr	372	236	0	0	85	32	11	5
May	327	27	33	10	148	32	16	11
Jun	198	11	22	0	91	14	0	0
Jul	610	251	88	54	27	1	0	3
Aug	429	161	39	17	127	62	0	0
Sep	8339	4361	534	325	2934	1509	14	8
Oct	469	170	44	13	471	94	11	2
Nov	229	38	7	3	172	46	2	0
Dec	160	59	5	3	324	224	4	9
Jan	60	25	6	0	256	108	5	0
Feb	50	8	10	0	2	1	1	0
Total	19,079	9126	1700	994	6091	2818	283	182
%	67.6	32.4	63	36.9	68.4	31.6	60.9	39

Appendix 2. **Distribution of *An. funestus* in Mbui Njeru and Mathangauta village by sex.**

	Mbui Njeru				Mathangauta			
	Indoors		Outdoors		Indoors		Outdoors	
	F	M	F	M	F	M	F	M
Apr 1989	3	1	1	0	3	1	0	0
May	0	0	2	0	13	0	2	1
Jun	9	2	3	0	15	1	3	0
Jul	32	5	24	5	19	4	26	18
Aug	5	2	3	1	6	5	13	3
Sep	0	0	0	0	7	1	0	0
Oct	0	0	0	0	3	0	0	0
Nov	1	4	0	0	27	8	8	4
Dec	17	7	2	0	322	184	13	12
Jan 1990	28	7	0	0	534	228	8	6
Feb	57	30	1	0	48	18	3	0
Mar	7	4	0	0	22	1	0	0
Apr	21	0	0	0	25	0	1	0
May	33	8	0	0	107	9	1	0
Jun	46	8	0	0	272	41	4	1
Jul	26	3	0	0	145	27	0	0
Aug	95	66	0	0	173	60	4	0
Sep	0	0	0	0	194	43	0	1
Oct	10	2	0	0	35	6	2	1
Nov	32	4	0	0	75	20	10	5
Dec	25	5	0	0	535	111	3	5
Jan 1991	13	7	9	3	550	139	6	0
Feb	7	6	3	1	109	21	1	0
Total	467	171	48	10	3239	928	108	57

Appendix 3. **Seasonal numbers of *An. arabiensis* mosquitoes in Mbui Njeru village collected using hand catch method from April 1989 to February 1991**

Month	Season	Paddy Cond.	Indoor Total Coll.	Indoor Mean/ House	Outdoor Total Coll.	Outdoor Mean/ Time
Apr 1989	Wet	F	284	71.0	19	1.3
May	Wet	F	334	83.5	38	2.5
Jun	Dry	F	518	129.5	52	3.5
Jul	Dry	F	372	93.0	47	3.1
Aug	Dry	F	1,037	259.3	160	10.7
Sep	Dry	F	4,625	1,156.3	575	38.3
Oct	Wet	F	2,793	698.3	462	30.8
Nov	Wet	F	592	148.0	109	7.3
Dec	Wet	F	226	56.5	11	0.7
Jan 1990	Dry	D	387	96.8	1	0.1
Feb	Dry	D	285	71.3	6	0.4
Mar	Wet	F	162	40.5	1	0.1
Apr	Wet	F	608	152.0	0	0
May	Wet	F	354	88.5	43	2.9
Jun	Dry	F	209	52.3	22	1.5
Jul	Dry	F	861	215.3	142	9.5
Aug	Dry	F	590	147.5	56	3.7
Sep	Dry	F	12,700	3,175.0	859	57.3
Oct	Wet	F	639	159.8	57	3.8
Nov	Wet	F	267	66.8	10	0.7
Dec	Wet	F	219	54.8	8	0.5
Jan 1991	Dry	D	85	21.3	6	0.4
Feb	Dry	D	58	14.5	10	0.7
Total			28,205		16752	
Mean			1,226		728	

F = Flooded
D = Dry
No. of Houses = 4
Time of collection outdoors = 15 minutes
Paddies flooded = 10 months/ year

Appendix 3.1 **Seasonal numbers of *An. funestus* in Mbui Njeru village collected using hand catch method from April 1989 to February 1991.**

Month	Season	Paddy Cond.	Indoors Total Coll.	Indoors Mean/ House	Outdoors Total coll.	Outdoors Mean/ Time
Apr 1989	Wet	F	4	1	1	0.07
May	Wet	F	0	0	2	0.1
Jun	Dry	F	11	2.8	3	0.2
Jul	Dry	F	37	8	29	1.9
Aug	Dry	F	7	1.8	4	0.3
Sep	Dry	F	0	0	0	0
Oct	Wet	F	0	0	0	0
Nov	Wet	F	5	1.3	0	0
Dec	Wet	F	24	6	2	0.1
Jan 1990	Dry	D	35	8.8	0	0
Feb	Dry	D	87	21.8	1	0.07
Mar	Wet	F	11	2.8	0	0
Apr	Wet	F	21	5.3	0	0
May	Wet	F	41	10.3	0	0
Jun	Dry	F	54	13.5	0	0
Jul	Dry	F	29	7.3	0	0
Aug	Dry	F	161	40.3	0	0
Sep	Dry	F	0	0	0	0
Oct	Wet	F	12	3	0	0
Nov	Wet	F	36	9	0	0
Dec	Wet	F	30	7.5	0	0
Jan 1991	Dry	D	20	5	12	0.8
Feb	Dry	D	13	3.3	4	0.3
Total			638		58	
Mean			28		3	

F = Flooded
D = Dry
Coll. = Collected
Cond. = Condition

Appendix 3.2 **Seasonal numbers of *An.arabiensis* in Mathangauta village collected using hand catch method from April 1989 to February 1991.**

Month	Season	Paddy cond.	Indoors Total coll.	Indoors Mean/ house	Outdoors Total coll.	Outdoors Mean/ time
Apr 1989	Wet	D	13	3.3	10	0.7
May	Wet	D	43	10.8	74	4.9
Jun	Dry	D	43	10.8	5	0.3
Jul	Dry	F	22	5.5	3	0.2
Aug	Dry	F	49	12.3	6	0.4
Sep	Dry	F	637	159.3	10	0.7
Oct	Wet	F	845	211.3	56	3.7
Nov	Wet	F	334	83.5	127	8.5
Dec	Wet	F	111	27.8	60	4
Jan 1990	Dry	D	1	0.3	1	0.07
Feb	Dry	D	2	0.5	8	0.5
Mar	Wet	D	49	12.3	3	0.2
Apr	Wet	D	117	29.3	16	1.07
May	Wet	D	180	45.0	27	1.8
Jun	Dry	D	105	26.3	0	0
Jul	Dry	F	28	7.0	3	0.2
Aug	Dry	F	189	47.3	0	0
Sep	Dry	F	4443	1110.8	22	1.5
Oct	Wet	F	639	159.8	57	3.8
Nov	Wet	F	218	54.5	2	0.1
Dec	Wet	F	548	137.0	13	0.9
Jan 1991	Dry	D	364	91	5	0.3
Feb	Dry	D	3	0.8	1	0.07
Total			8983		626	
Mean			391		27	

Appendix 3.3 **Seasonal numbers of *An. funestus* in Mathangauta village collected using hand catch method from April 1989 to February 1991.**

Month	Season	Paddy cond.	Indoor Total coll.	Indoor Mean/ house	Outdoor Total coll.	Outdoor Mean/ time
Apr 1989	Wet	D	4	1.0	0	0
May	Wet	D	13	3.3	3	0.2
Jun	Dry	D	16	4.0	3	0.2
Jul	Dry	F	23	5.8	44	2.9
Aug	Dry	F	11	2.8	16	1.1
Sep	Dry	F	8	2	0	0
Oct	Wet	F	3	0.8	0	0
Nov	Wet	F	35	8.8	12	0.8
Dec	Wet	F	506	126.5	25	1.7
Jan 1990	Dry	D	762	190.5	14	0.9
Feb	Dry	D	66	16.5	3	0.2
Mar	Wet	D	23	5.8	0	0
Apr	Wet	D	25	6.3	1	0.07
May	Wet	D	116	29.0	1	0.07
Jun	Dry	D	313	78.3	5	0.3
Jul	Dry	F	172	43.0	0	0
Aug	Dry	F	233	58.3	4	0.3
Sep	Dry	F	237	59.3	1	0.07
Oct	Wet	F	41	10.3	3	0.2
Nov	Wet	F	95	23.8	15	1
Dec	Wet	F	646	161.5	8	0.5
Jan 1991	Dry	D	689	172.3	6	0.4
Feb	Dry	D	130	32.5	1	0.07
Total			4167		165	
Mean			181		7	

Appendix 3.4 **Seasonal numbers of *An. arabiensis* in Mbui Njeru village collected using hand and pyrethrum spray catch methods from February 1990 to February 1991.**

Month	Season	Paddy Cond.	Hand collection Total Coll.	Hand collection Mean/ House	Pyrethrum Spray Total Coll.	Pyrethrum Spray Mean/ House
Feb 1990	Dry	D	80	20.0	269	67.3
Mar	Wet	F	35	8.8	114	28.5
Apr	Wet	F	121	30.3	198	49.5
May	Wet	F	65	16.3	233	58.3
Jun	Dry	F	27	6.8	93	23.3
Jul	Dry	F	142	35.5	327	81.8
Aug	Dry	F	207	51.8	40	10.0
Sep	Dry	F	1,348	37.0	13,554	3388.5
Oct	Wet	F	122	30.5	353	88.3
Nov	Wet	F	66	16.5	134	33.5
Dec	Wet	F	46	11.5	184	46.0
Jan 1991	Dry	D	41	10.3	69	17.3
Feb	Dry	D	17	4.3	30	7.5
Total			2,317	579.3	15,598	3899.5
Mean			178	44.5	1200	299.9

F = Flooded
D = Dry
Cond. = Condition
Coll. = Collected

Appendix 3.5 **Seasonal numbers of *An. arabiensis* in Mathangauta village collected using hand and pyrethrum spray catch methods from February 1990 to February 1991.**

Month	Season	Paddy Cond.	Hand collection Total Coll.	Hand collection Mean/ House	Pyrethrum Spray Total Coll.	Pyrethrum Spray Mean/ House
Feb 1990	Dry	D	2	0.5	13	3.3
Mar	Wet	D	19	4.8	21	5.3
Apr	Wet	D	115	28.8	0	0
May	Wet	D	21	4.2	22	5.5
Jun	Dry	D	28	4.0	25	6.3
Jul	Dry	F	15	3.8	4	1.0
Aug	Dry	F	303	75.8	69	17.3
Sep	Dry	F	273	68.3	5463	1365.8
Oct	Wet	F	106	26.5	227	56.8
Nov	Wet	F	51	12.8	114	28.5
Dec	Wet	F	103	25.8	269	67.3
Jan 1991	Dry	D	116	29.0	183	45.8
Feb	Dry	D	3	0.8	0	0
Total			1155	285.1	6410	1602.9
Mean			89	21.9	493	123.3

F = Flooded
D = Dry
Cond. = Condition
Coll. = Collected

Appendix 3.6 Seasonal numbers of *An. funestus* in Mbui Njeru village collected using hand and pyrethrum spray catch methods from February 1990 to February 1991.

Month	Season	Paddy Cond.	Hand collection Total coll.	Hand collection Mean/ house	Pyrethrum S. C. Total coll.	Pyrethrum S. C. Mean/ house
Feb 1990	Dry	D	7	1.8	36	9.0
Mar	Wet	F	6	1.5	5	1.3
Apr	Wet	F	17	4.3	0	0
May	Wet	F	12	3.0	21	5.3
Jun	Dry	F	15	3.8	16	4
Jul	Dry	F	16	4.0	7	1.8
Aug	Dry	F	37	9.3	90	22.5
Sep	Dry	F	0	0	0	0
Oct	Wet	F	8	2	1	0.3
Nov	Wet	F	25	6.3	5	1.3
Dec	Wet	F	8	2	1	0.3
Jan 1991	Dry	D	20	5	14	3.5
Feb	Dry	D	8	2	0	0
Total			179	45.0	196	49.3
Mean			14	3.5	15	3.8

F = Flooded
D = Dry
Cond. = Condition
Coll. = Collected

Appendix 3.7 **Seasonal numbers of *An. funestus* in Mathangauta village collected using the hand and pyrethrum spray catch methods from February 1990 to 1991.**

Month	Season	Paddy cond.	Hand collection Total coll.	Hand collection Mean/ house	Pyrethrum S.C. Total coll.	Pyrethrum S.C. Mean/ house
Feb 1990	Dry	D	49	12.3	44	11.0
Mar	Wet	D	16	4	5	1.3
Apr	Wet	D	18	4.5	0	0
May	Wet	D	10	2.5	16	4
Jun	Dry	D	90	22.5	47	11.8
Jul	Dry	F	53	13.3	50	12.5
Aug	Dry	F	53	13.3	72	18.0
Sep	Dry	F	15	3.8	124	31.0
Oct	Wet	F	24	6.0	10	2.5
Nov	Wet	F	38	9.5	10	2.5
Dec	Wet	F	97	24.3	114	28.5
Jan 1991	Dry	D	540	135.0	321	80.3
Feb	Dry	D	23	5.8	17	4.3
Total			1026	256.8	830	207.70
Mean			79	19.8	64	15.97

F = Flooded
D = Dry
Cond. = Condition
Coll. = Collected

Appendix 3.8 **Seasonal numbers of *An. arabiensis* and *An. funestus* collected in Mbui Njeru by CDC light trap from February 1990 to February 1991.**

Month	Season	Paddy cond.	Species *A. arabiensis*		*A. funestus*	
			n	%	n	%
Feb 1990	Dry	D	65	3.3	0	0
Mar	Wet	F	22	1.1	5	7.1
Apr	Wet	F	85	4.3	20	28.6
May	Wet	F	52	2.7	0	0
Jun	Dry	F	86	4.4	23	32.9
Jul	Dry	F	316	16.1	0	0
Aug	Dry	F	49	2.5	0	0
Sep	Dry	F	884	45.1	0	0
Oct	Wet	F	180	9.2	0	0
Nov	Wet	F	108	5.5	3	4.3
Dec	Wet	F	59	3.0	0	0
Jan 1991	Dry	D	35	1.8	19	27.1
Feb	Dry	D	21	1.1	0	0
TOTAL			1962		70	
Mean			83		5	

F = Flooded
D = Dry
n = numbers collected
% = Percentage

Appendix 3.9 Seasonal numbers of *An. arabiensis* and *An. funestus* collected in Mathangauta by the CDC light trap from February 1990 to February 1991.

Month	Season	Paddy cond.	Species			
			A. arabiensis		*A. funestus*	
			n	%	n	%
Feb 1990	Dry	D	0	0	0	0
Mar	Wet	D	0	0	0	0
Apr	Wet	D	0	0	0	0
May	Wet	D	18	1.7	40	3.1
Jun	Dry	D	33	3.0	80	6.1
Jul	Dry	F	7	0.6	44	3.4
Aug	Dry	F	82	7.6	133	10.2
Sep	Dry	F	528	48.8	98	7.5
Oct	Wet	F	166	15.3	3	0.2
Nov	Wet	F	92	8.5	18	1.4
Dec	Wet	F	82	7.6	442	33.7
Jan 1991	Dry	D	75	6.9	368	28.1
Feb	Dry	D	0	0	84	6.4
Total			1083		1310	
Mean			83		101	

F = Flooded
D = Dry
n = number collected
% = Percentage

Appendix 3.10. Monthly height of rice in paddies found in Mbui Njeru village.

Month	Season	Ann. Rainfall	Paddy condition	Average height of rice (cm)
Apr 1989	Wet	242.8	Flooded	0
May	Wet	85.6	Flooded	0
Jun	Dry	14.1	Flooded	0
Jul	Dry	6.9	Flooded	20.0
Aug	Dry	14.4	Flooded	34.7
Sep	Dry	42.0	Flooded	71.1
Oct	Wet	97.9	Flooded	92.5
Nov	Wet	245.7	Flooded	106.0
Dec	Wet	106.3	Flooded	123.0
Jan 1990	Dry	14.2	Dry	137.0
Feb	Dry	35.1	Dry	140.0
Mar	Wet	226.9	Flooded	0
Apr	Wet	419.3	Flooded	0
May	Wet	165.2	Flooded	0
Jun	Dry	1.2	Flooded	0
Jul	Dry	18.3	Flooded	20.0
Aug	Dry	5.9	Flooded	34.7
Sep	Dry	34.8	Flooded	81.1
Oct	Wet	185.0	Flooded	94.5
Nov	Wet	144.8	Flooded	106.0
Dec	Wet	132.5	Flooded	130.0
Jan 1991	Dry	3.3	Dry	142.0
Feb	Dry	0	Dry	144.0
Total		2242.2		
Mean		97.4		

Appendix 3.11. Monthly height of rice in paddies found in Mathangauta village.

Month	Seaso	Ann. Rainfall (mm)	Paddy condition	Average rice height (cm)
Apr 1989	Wet	242.8	Dry	0
May	Wet	85.6	Dry	0
Jun	Dry	14.1	Dry	0
Jul	Dry	6.9	Flooded	0
Aug	Dry	14.4	Flooded	20.0
Sep	Dry	42.0	Flooded	40.0
Oct	Wet	97.9	Flooded	48.0
Nov	Wet	245.7	Flooded	56.0
Dec	Wet	106.3	Flooded	110.0
Jan 1990	Dry	14.2	Dry	120.0
Feb	Dry	35.1	Dry	135.0
Mar	Wet	226.9	Dry	0
Apr	Wet	419.3	Dry	0
May	Wet	165.2	Dry	0
Jun	Dry	1.2	Dry	0
Jul	Dry	18.3	Flooded	0
Aug	Dry	5.9	Flooded	25.0
Sep	Dry	34.8	Flooded	42.0
Oct	Wet	185.0	Flooded	50.0
Nov	Wet	144.8	Flooded	54.0
Dec	Wet	132.5	Flooded	100.0
Jan 1991	Dry	3.3	Dry	130.0
Feb	Dry	0	Dry	138.0
Total		2242.2		
Mean		97.5		

Appendix 3.12 Monthly distribution of *An. arabiensis* larvae in Mbui Njeru and Mathangauta.

Month	Village: Mbui Njeru Height of rice (cm) (x)	Mbui Njeru Average/ dip (y)	Mathangauta Height of rice (cm) (x)	Mathangauta Average/ dip (y)
Apr 1989	0	0	0	0
May	0	0	0	0
Jun	0	22	0	1
Jul	20	4	0	6
Aug	34.7	212	20.0	20
Sep	71.1	36	40.0	10
Oct	92.5	45	48.0	191
Nov	106.0	4	56.0	6
Dec	123.0	98	110.0	45
Jan 1990	137.0	20	120.0	10
Feb	140.0	18	135.0	8
Mar	0	5	0	3
Apr	0	0	0	0
May	0	0	0	0
Jun	0	18	0	11
Jul	20.0	315	0	312
Aug	34.7	121	25.0	12
Sep	81.1	22	42.0	156
Oct	94.5	30	50.0	17
Nov	106.0	17	54.0	2
Dec	130.0	23	100.0	13
Jan 1991	142.0	18	130.0	51
Feb	144.0	5	138.0	9
Total		1033.0		883.0

Correlation Coefficient (r)
Mbui Njeru = -0.118
Mathangauta = -0.076

Appendix 3.13. Mean numbers of adult *An. arabiensis* from the different houses in Mbui Njeru and Mathangauta.

Month	Mbui Njeru				Mathangauta			
	House number							
	1	2	3	4	1	2	3	4
Distance from Paddies (m)	58	63	76	88	66	72	72	63
Apr 1989	66	55	54	35	26	4	0	0
May	174	98	105	25	25	12	3	3
Jun	161	40	55	136	22	0	5	8
Jul	67	99	144	42	12	3	1	5
Aug	336	197	382	122	35	6	2	21
Sep	1507	947	1670	710	267	159	72	139
Oct	535	637	645	1548	442	52	117	234
Total	2846	2073	3055	2618	829	236	200	410
Mean	407	296	436	374	118	33	29	59

Appendix 4. **Resting behaviour of *An. arabiensis*, *An. funestus* and *An. rufipes*.**

Month	Species	Mbui Njeru IN	Mbui Njeru OUT	Mathangauta IN	Mathangauta OUT
April 1989	*An. arabiensis*	284	19	13	10
	An. funestus	3	1	4	0
	An. rufipes	2	7	2	100
May	*An. arabiensis*	334	39	43	74
	An. funestus	0	2	13	3
	An. rufipes	0	1	1	150
June	*An. arabiensis*	518	52	43	5
	An. funestus	11	3	16	3
	An. rufipes	1	0	1	157
July	*An. arabiensis*	372	47	13	12
	An. funestus	56	10	45	22
	An. rufipes	0	140	0	110
August	*An. arabiensis*	1037	160	49	17
	An. funestus	7	3	11	16
	An. rufipes	34	10	0	69
Sept.	*An. arabiensis*	4625	575	637	11
	An. funestus	0	0	8	0
	An. rufipes	3	56	0	79
Oct.	*An. arabiensis*	2793	462	845	56
	An. funestus	0	0	3	0
	An. rufipes	0	0	0	90
Nov.	*An. arabiensis*	592	109	334	127
	An. funestus	5	0	35	12
	An. rufipes	1	2	0	134
Dec.	*An. arabiensis*	236	11	111	60
	An. funestus	24	2	506	25
	An. rufipes	0	5	1	18
Jan. 1990	*An. arabiensis*	387	1	1	1
	An. funestus	35	0	762	14
	An. rufipes	0	0	0	2
Feb.	*An. arabiensis*	285	6	2	0
	An. funestus	87	1	66	3
	An. rufipes	0	0	0	0

Mar.	*An. arabiensis*	162	1	49	3
	An. funestus	11	0	23	0
	An. rufipes	0	1	0	9
Apr.	*An. arabiensis*	608	0	118	16
	An. funestus	21	0	25	1
	An. rufipes	0	0	1	25
May	*An. arabiensis*	354	43	180	27
	An. funestus	41	0	116	1
	An. rufipes	0	0	8	87
June	*An. arabiensis*	209	22	105	0
	An. funestus	54	0	313	5
	An. rufipes	1	0	8	106
July	*An. arabiensis*	861	142	28	0
	An. funestus	29	0	172	0
	An. rufipes	0	0	6	45
Aug.	*An. arabiensis*	590	56	189	0
	An. funestus	161	0	233	4
	An. rufipes	0	0	0	202
Sep.	*An. arabiensis*	12,700	859	4443	14
	An. funestus	0	0	237	1
	An. rufipes	1	0	3	6
Oct.	*An. arabiensis*	639	57	565	13
	An. funestus	12	0	41	3
	An. rufipes	1	0	2	86
Nov.	*An. arabiensis*	267	10	218	2
	An. funestus	36	0	95	15
	An. rufipes	0	0	0	0
Dec.	*An. arabiensis*	165	62	548	13
	An. funestus	30	0	30	0
	An. rufipes	0	0	0	21
Jan.	*An. arabiensis*	85	6	364	5
	An. funestus	20	0	689	6
	An. rufipes	0	0	4	1
Feb.	*An. arabiensis*	58	10	3	1
	An. funestus	13	4	130	1
	An. rufipes	0	0	1	0

Appendix 5.8. Malaria prevalence of residents of Kano Plains Nyando Division, Western Kenya.

Age Group	No. Examined	No. Positive	Parasite rate %
0-11 months	23	17	73.9
12-23 months	22	18	81.8
2-4 years	89	78	87.6
5-9 years	286	177	61.9
10-14 years	257	141	54.9
15+	257	87	33.9
Total	934	518	55.5